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PREFACE

Finland has organised two International Conferences on Climate and Water, in August 1989 and in September 1998. Please find here **the Proceedings of the Third International Conference on Climate and Water, Helsinki, 3–6 September 2007.**

The objective of this Conference has been to provide an opportunity for hydrologists, water managers and decision makers to exchange research results, ideas and concerns on impacts, adaptation and mitigation in the water sector, facing climate change.

- How have we proceeded since 1998?
- What are major challenges today?
- Where are we going?
- Where should we go?

The proceedings contain around 90 papers on various themes related to the complex relationship between climate and water. The papers are in alphabetical order according to the first author. This turned out to be the only logical way, because classification according to the topic would not have been very clear.

After the full papers, there are a number of abstracts, again in alphabetical order according to the first author. This section includes those oral and poster presentations, whose authors have not sent a full paper.

Some authors could not participate the conference. Their contributions have also been included, because the final list of participants was still unknown when the material was printed.

Some editing has been made, but the organisers have not made any corrections to language or any typographic changes.

As representatives of the main organiser, Finnish Environment Institute, we like to thank all our Finnish and international partners for their efforts to make this Conference successful. We have received financial support from the Ministry of Agriculture and Forestry, the Ministry of the Environment, the Ministry for Foreign Affairs and the Academy of Finland. Other Finnish partners include Helsinki University of Technology, Finnish Meteorological Institute and Vaisala. Our international co-organisers have been the European Union, World Meteorological Organisation, Unesco, International Association of Hydrological Sciences, and International Water Resources Association.

Last but not least – the organisers like to thank all participants for making a successful Conference!

July 2007

Esko Kuusisto
Chairman of the Scientific Committee

Markku Puupponen
Chairman of the Organizing Committee

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Predicting water temperatures based on air temperatures and estimating the effects of climate change

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Keywords: River temperature, estimation, climate change

ABSTRACT

Effects of climate change on river temperatures are important from the viewpoint of the possible ecological status and water quality changes. There are several statistical approaches to investigate the relationship between water temperature and air temperature. Multiple regression and ANOVA can be applied to decide on the importance and the relative effects of the selected parameters or factors. In this study a relationship is formulated between water temperature and air temperature and the effects of air temperature measured on days preceding the water temperature measurement together with discharge are investigated. Since the water temperature can be affected by air temperature but the responses are obtained with a lag due to heat transfer limitations, air temperature for a given day together with temperatures of 1st, 2nd, 3rd, 4th and 5th days before are analyzed to identify the impacts on water temperature. Effects of mean, minimum and maximum temperatures and also the preceding 5-day averages on water temperature are investigated. For this purpose the Porsuk Stream which is the main tributary of the Sakarya River located in the Middle Anatolian Region of Turkey is selected and data spanning a period of 24 years are used to obtain regression equations. At the end of the statistical analysis an optimum model for the estimation of the water temperature related to the air temperature is found. The model equations are used to predict water temperatures based on increasing air temperatures due to global warming and climate change.

INTRODUCTION

Water temperature is a crucial parameter for aquatic environments. It is a primary physical property because it exerts a significant influence on many parameters of water quality, affects human uses of water and the management of river systems (Webb and Nobilis, 1994). Studies related to long term changes of water temperatures are necessary to determine the current status and predict future influences in order to decide how management strategies can be developed. According to IPCC (Intergovernmental Panel on Climate Change) reports there is no doubt that there is an increasing trend in average global air temperatures and temperatures within 1.5 – 4 °C are expected towards 2100 (IPCC, 2007). In this report a warming of about 0.2°C per decade is projected for the next two decades. Due to these facts, the possible effects of these predictions on watercourses must also be investigated in all regions.

The Mediterranian region is expected to be influenced quite negatively as also reported in IPCC, 2007. The precipitation is projected to decrease in this region and droughts are expected. Therefore the water resources will become more and more important, especially those used for multiple purposes. Such water supplies must be investigated for temperature trends and depending on the future expectations precautions must be taken into account.

There are studies relating water temperatures to environmental parameters. Mohseni and Stefan (1999) have analyzed stream temperature/air temperature relationship by studying the heat exchange processes using the equilibrium temperature concept. River temperature sensitivity to hydraulic and meteorological parameters have been studied by Gu and Li (2002). They have found that river temperatures are more sensitive to flowrates, upstream inflow temperatures, air temperatures, humidity and solar radiation than to other parameters like wind speed and morphometry. It is also stated in their study that river temperatures are affected by flow and weather and that both are significant.

In this study water temperatures are analysed together with the air temperatures and river discharges and the possible impacts of these on the river temperatures are investigated for a river in the Middle Anatolian Region of Turkey. The models are designed in such a way as to achieve the desired information with the smallest data set possible. The input required for these models should be already present, i.e. a subset of regular observations made at stream monitoring stations and meteorological stations. Thus no additional data requirements will be necessary.

THE STUDY AREA

The Porsuk river is an important source of fresh water for the Eskişehir and Kütahya regions in Turkey. This river and its tributaries are mainly used for the purposes of irrigation, drinking water supply, industrial water supply, recreation, fishery and, municipal and industrial waste disposal by Kütahya and Eskişehir (EÇDR, 2005). Figure 1 shows the location of the study area and the Porsuk River watershed in Eskişehir, Turkey.

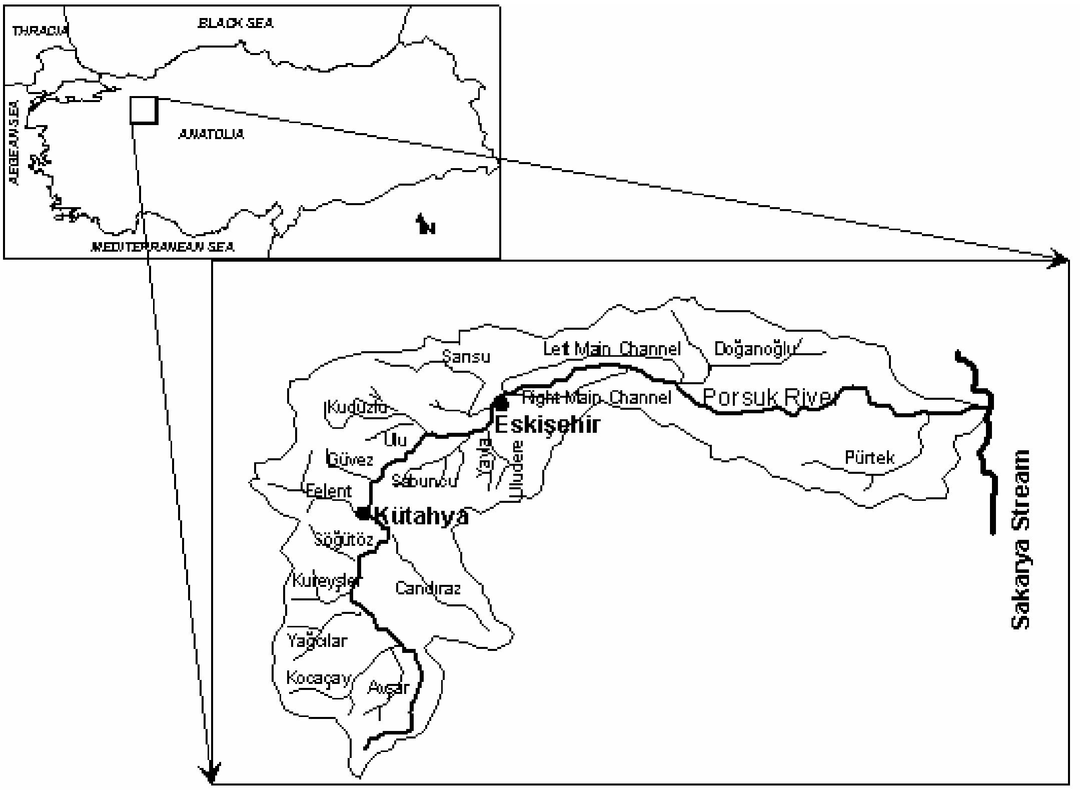

Fig 1. Watershed of the Porsuk river and its location within Turkey

The river is flowing through agricultural basins and two relatively large cities. There are also important industrial facilities located along the river. The river is thus polluted by a number of point sources and diffuse sources are also contributing to the pollutant load of the river.

METHODS

The data used in this study belong to a monitoring station situated at the Porsuk river between the city of Kütahya and the Porsuk reservoir. The Beşdeğirmen station has been used for a long time by state agencies which monitor discharge and water quality at stations situated on Turkish streams. The data used in this study have been obtained from the published data source (EIE, 2000). The air temperatures have been obtained from the State Meteorological Agency of Turkey.

A total of 280 records for river temperatures and discharges have been utilized in this study. The data belongs to a period between 1975 and 2000 and consist of monthly instantaneous measurements of the relevant parameters. The air temperature data is daily (means, minimums and maximums), but only measurements taken on the day the river measurements have been made are utilized. Also air temperatures for the five days preceding the measurement day have been used. The data show that there is an inverse relationship between river discharge and water temperature. This is a generally observed result both for natural watercourses and for rivers receiving heated effluents. The relationship between the discharge and water temperature is given in the following plot. The correlation coefficient for the 280 data pairs is -0.34. The relationship is not strong but significant. Figure 2 shows this relationship.

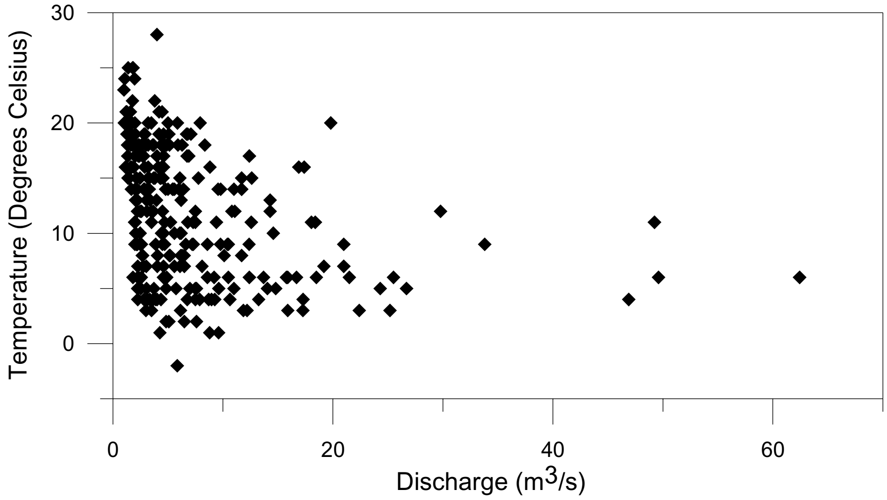

Figure 2. The relationship between air temperature and discharge

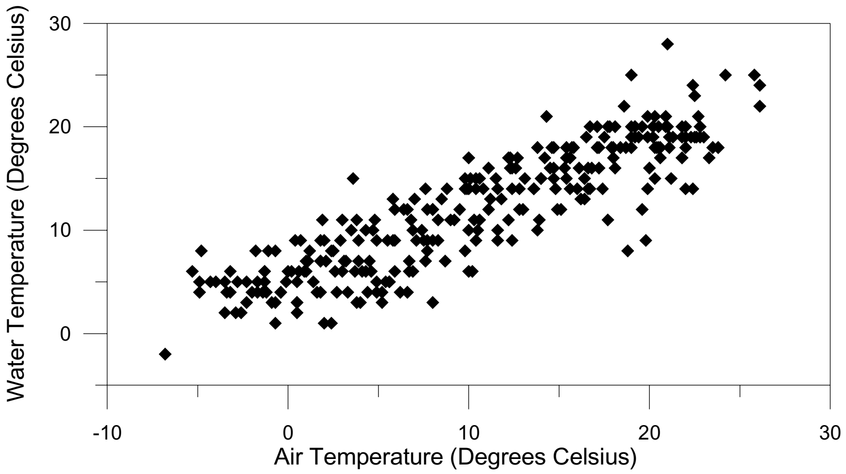

Figure 3. The relationship between air temperature and water temperature

The correlation between the air and water temperatures is positive and higher with a correlation coefficient of 0.88 as expected as shown in Figure 3.

The relationship between the water temperature and the mean of the preceding 5 day temperatures and minimum and maximum temperatures is also positive and of similar magnitude.

Six models have been developed to predict water temperature based on the above mentioned parameters. The models are linear multiple regression models with water temperature as the criterion variable. The predictor variables are river discharge and various air temperatures statistics. Though the river discharge explains around 34% of variation in water temperatures alone compared with 88% for the air temperatures, it has been included in 3 models. This is due to the fact that river discharges will be affected by climate change to a large extent and is expected to affect water temperatures in this way. Table 1 presents these models.

Table 1. Models used in predicting water temperatures

Models	**Functions of Predictor Variables** **fn (Predictor Variable 1, Predictor Variable 2, ……)**
Model 1	fn (River discharge, Air temperature)
Model 2	fn (Air temperature)
Model 3	fn (River discharge, Mean of 6 day air temperature)
Model 4	fn (Mean of 6 day air temperature)
Model 5	fn (River discharge, Maximum temperature, Minimum temperature)
Model 6	fn (Maximum temperature, Minimum temperature)

RESULTS AND DISCUSSION

Regression analysis has been conducted using the 280 data pairs and the above models. The regression results are presented in Table 2.

Table 2. The regression results

	Intercept	Predictor Variable Coefficients					R^2
		River discharge	Air Temperature	Mean of 6 day air temperature	Maximum temperature	Minimum temperature	
Model 1	6.32	-0.11	0.62				0.79
Model 2	5.32		0.65				0.78
Model 3	5.87	-0.10		0.66			0.80
Model 4	4.95			0.69			0.78
Model 5	6.65	-0.11			0.25	0.41	0.80
Model 6	5.61				0.27	0.42	0.78

It can be seen from the results in Table 2 that all models possess similar R^2 values, meaning that these models will perform similarly. So in the case of missing predictor variable data, there are always alternative models to be used which will predict water temperatures with almost equal certainty. In all models, all the predictor coefficients are significant. When the river discharge is included in the regression equations, the R^2 value is always a little higher that the corresponding model without the river discharge. Thus the river discharge can be included to improve the regression slightly. But the main reason to use the river discharge is to predict the water temperatures when trends in discharges are present due to climate change.

It has been observed from the data that there is a decreasing trend in river discharges in the 25 year period. This decrease has a number of reasons. One reason is the increased amount of abstractions from the river for various purposes. Another reason is the decrease in precipitation experienced over the watershed in the last decade of the twentieth century (FNCCC, 2007). The magnitude of the trend based on a linear regression equation between discharge and months is -0.0277 m^3/s per month. Thus the yearly trend is 0.33 m^3/s. This decreasing trend acts in a way to increase the water temperatures as temperature is inversely related to discharge.

Observations in temperatures show a similar but reverse pattern. Air temperatures have increased in most parts of Turkey (FNCCC, 2007). The trend in the 6 day mean temperatures is 0.0053 degrees Celsius per month, totaling to a yearly of 0.06 degrees Celsius. When the temperature increase continues at this magnitude, there will be a total increase of 3.2 degrees Celsius in 2050 compared to year 2000 values. This is a high increase compared to predictions, but local effects may be present in the observations.

Predictions by Model 3 give a trend magnitude of 0.0064 degrees Celsius per month. This trend is a combination of trends in air temperatures and river discharges which together act to reinforce each other. Figure 4 shows the plot of Model 3 together with the observations.

When air temperature trends and discharge trends continue in this pattern, it can be said that the water temperatures will rise by a few degrees Celsius. The magnitude can be calculated more exactly by making reliable predictions of future air temperatures and river discharges. When the trends continue by the amounts stated above an increase of 3.8 degrees Celsius by the year 2050 as compared to year 2000 can be expected. This value is again a high value as it is based on the high air temperature trend. But even an increase in magnitude half this value will be important from the viewpoint of the river ecosystem.

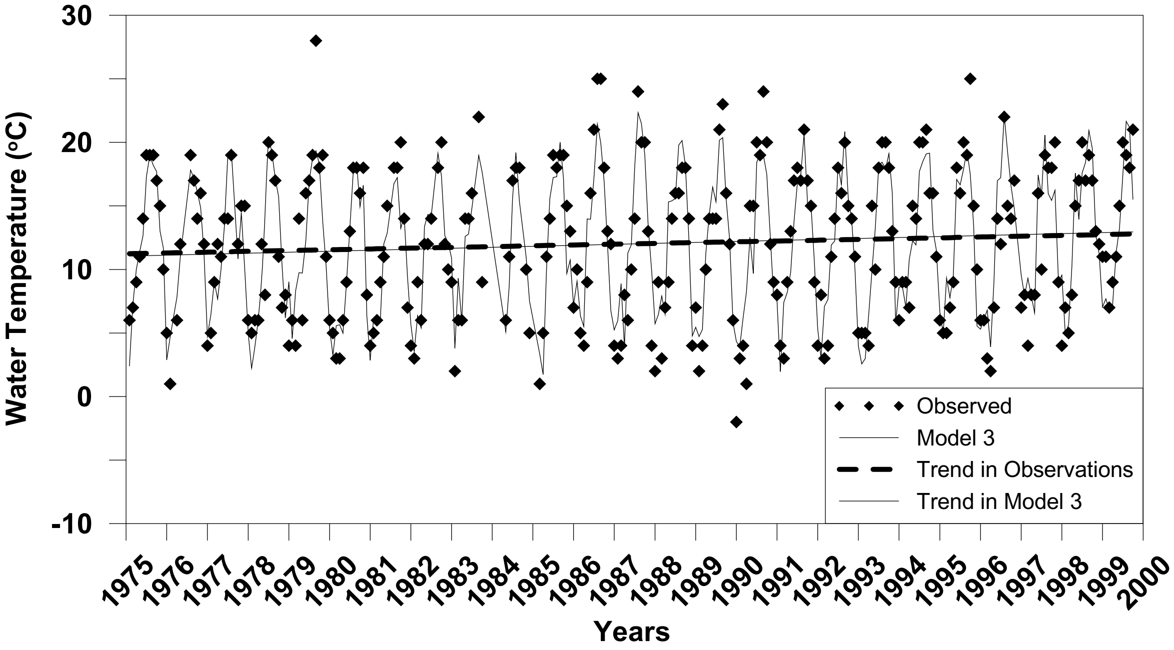

Figure 4 Comparison of Model 3 Results with observed data

CONCLUSION

Simple models have been constructed to predict rivers water temperatures based on air temperatures and river discharge. These regression models utilize data which are measured at almost every river monitoring station and meteorological station and can be quite easily found and manipulated. All models give similar results and each can be used in place of the other. These models can be utilized to predict water temperatures in the future or under extreme conditions like in periods of extreme temperatures.

The odd-numbered models incorporate the river discharge which is expected to increase or decrease due to climate change. This trend can be of importance in determining in stream temperatures. So when discharge data is available together with some form of air temperature data (daily mean, extremes or means of preceding days) it is advisable to include it in the regression models. In some rivers the relationship between discharge and water temperature may be different than in the Porsuk river. These models are river-specific and for each river different sets of equations must be developed.

ACKNOWLEDGEMENTS

The authors are indebted to the staff of EİE, General Directorate of Electrical Power Resources Survey and Development Administration of Turkey for collecting, analysisng and publishing data about Turkish rivers. The authors also express their thanks to the State Meteorological Agency of Turkey for supplying them with meteorological data.

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Flood Scenario Studies in SW Finland

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Keywords: Flood risk map, climate change, Finland, hydrological simulation, hydraulic modeling

ABSTRACT

Floods in Finland are usually related to snow melt, ice jamming, as well as torrential and prolonged rain events. These phenomena follow a typical seasonal cycle, and have a characteristic regional occurrence. The most widespread floods take place in the spring during the snowmelt season. Recently, however, spring floods have been less pronounced in southern Finland due to repeated snowmelts during winter. Predicted climate changes may dramatically alter these conditions and further increase flooding in Finland. According to regional climate models (e.g. RCAO), the mean temperature will rise 4–5 °C in winter and 2–3 °C in summer, with a precipitation increase of 20–30%. In addition, a particularly Finnish characteristic in future flooding events includes land uplift due to post-glacial rebound, whereby channel gradients will decrease significantly, as uneven land uplift will change relative elevations. The highest predicted land uplift rate, i.e. up to 90 cm/100a, along the coastal areas of Western Finland will also affect estuary formations in combination with erosion-transportation-sedimentation processes. In this paper, we present flood scenarios in the year 2071–2100 for the city of Pori, south western Finland, including flood hazard and flood risk maps. Future discharge estimations for the next 100 years were undertaken using the Watershed Simulation and Forecast System (WSFS) with HQ1/100a & HQ1/250a. The input climate data, i.e. HadAM3H & ECHAM4/OPYC3 scenarios with A2 & B2 emission scenarios, were down-scaled with the Swedish regional climate model RCAO with a WSFS simulated 3–24% increase in HQ 1/100a & 1/250a discharges for Pori by the year 2071–2100. Hydraulic modelling results confirmed increased inundations in these areas. Results indicated more severe flooding and altered flow conditions in south western Finland in the future. In addition, flood risk mapping was undertaken by combining both flood hazard maps and spatial databases of urban infrastructures.

INTRODUCTION

Between 1998 and 2002, over 100 major damaging floods occurred in Europe, causing *ca.* 700 casualties and the displacement of half a million people, and financial losses in excess of 25 billion euros (EC, 2005). Flooding in Finland is also an increasingly important socio-economic issue. The flood hazards of summer 2004 resulted in compensation claims of over 7 million euros, while in 2005, the northern province of Lapland suffered spring flood losses of over 5 million €. It has also been roughly estimated that in Finland, extreme flood events (HQ 1/250a) would cause potential damages of 550 million euros (Ollila *et al.,* 2000). Such flood hazards and preliminary flood damage estimations have strengthened public debate about how the government should act to protect the infrastructure and cover damages to private property.

In Finland, flooding is usually related to snowmelt, ice jamming, torrential and prolonged rain events within a typical seasonal cycle, with the most widespread floods take place in spring during the snowmelt season. Predicted climate changes may alter these conditions considerably and further increase inundations in Finland. According to regional climate models, i.e. the RCAO, the mean temperature will rise 4–5 °C in winter and 2–3 °C in summer, with a precipitation increase of 20–30%.

In digitally-aided flood mapping, the terms ‘flood mapping’, ‘flood risk’, and ‘flood hazard’ have been broadly used. More recently, these terms have been strictly defined internationally by the EC (2005) and Floodsite (2005), and nationally by the EXTREFLOOD research project (Sane *et al*., 2006). We have two different main products of flood mapping. Firstly, the flood hazard map is defined as a map showing those areas where floods are to be expected, including the flood probability and the degree of danger (e.g. water depth, flow velocity or a combination of these) (Sane et al., 2006). Secondly, the flood risk map is defined as showing both the inundated area and flood damages. The flood risk map represents flood damages with a certain return period, e.g. HQ 1/250a. In other words, the flood risk map is a function of flood hazard and vulnerability (populace, infrastructure, financial damages or environmental hazards) (cf. Floodsite, 2005; Sane *et al.,* 2006).

In hydrogeographical studies (cf. Reinfelds *et al.,* 2004; Alho *et al.,* 2005), both spatial databases and geoinformatics have been used. The most common utilisation of remote sensing methods is probably inundation mapping based on satellite remote sensing, or from the interpretation of aerial photographs (e.g. Currey, 1977; Alsdorf *et al.,* 2000; Horritt *et al.,* 2001). The acquisition and manipulation of digital terrain models (DTM) has also been used for hydraulic modelling purposes (Hunter *et al.,* 2005) and more generally in flood studies (Zerger, 2002). In addition, flow parameters have been calculated and flood hazard maps processed in a GIS (Geographical Information Systems) environment (Townsend *et al.,* 1998).

The objective of this paper is to demonstrate the coupling of discharge estimations in the years 2071–2100 by the Watershed Simulation and Forecast System (WSFS) and a hydraulic modelling procedure which includes GIS-aided flood risk mapping. In this paper, we present a pilot implication of the approach for the city of Pori, south western Finland.

STUDY AREA

The city of Pori, with *ca.* 76000 inhabitants, is located on the drainage basin of the Kokemäenjoki River which covers a total area of 27000 km^2, of which 11% is lake cover. A large proportion of the watershed is regulated due to both hydroelectric power production and flood protection. The Kokemäenjoki River delta is the largest in Scandinavia and belongs to the European Union Natura 2000 protection network. There is a major threat of flooding along the lower reaches and river mouth near Pori city. Although the last major flood hazard occurred over 25 years ago, with dozens of damaged buildings, repeated minor flood damages to summer cottages at the mouth of Kokemäenjoki River occur annually.

METHODS & DATA

The process chain of future flood risk mapping was based on three different modelling parts: hydrological simulation, hydraulic modelling and GIS-based overlay analysis. Firstly, future discharge simulation was undertaken using the Watershed Simulation and Forecasting System (WSFS). WSFS was developed and operated by the Finnish Environment Institute (Vehviläinen *et al.,* 2005). The WSFS is a conceptual watershed model based on the Swedish HBV-model and describes the physical processes of the water cycle in a simplified way. The WSFS model is comprised of small sub-basins each with its own set of parameters and has been calibrated using about 20 years of weather and watershed observations. Model simulations based on design precipitation were used in the simulation of the 1/100a and 1/250a floods. Here, design precipitation was combined with other severe conditions in the watershed. This method can be used to simulate floods with an approximate return period of 100-10 000 years, although it was originally developed for the estimation of design floods with a return period of 5 000-10 000 years (Veijalainen and Vehviläinen, 2006). The magnitude and approximate return period of the floods produced can be changed by changing the return period and magnitude of the design precipitation. For the simulation of the 1/100 and 1/250 year floods, design precipitations of 1/5 and 1/15 year respectively were used. The method has been applied from the Swedish dam design flood calculation method (Flödeskommittén 1990). In this applied approach, the design flood was calculated by combining the worst possible rare weather conditions. The 14 day design precipitation period (Solantie and Uusitalo 2000) is moved day by day through 40 years of weather data of temperatures and precipitation based on observations between 1961 and 2000. The most severe flood was sought out and this was considered to be the design flood. Simulations were repeated for the conditions of 2071-2100 and simulated floods compared. Potential future climate change by 2071-2100 was taken into consideration by changing both the areal temperatures and precipitations using the method of delta change based on observations between 1961 and 2001. The climate scenarios used for 2071-2100 which were from GCM's HadAM3H (H) and ECHAM4/OPYC3 (E) with emission scenarios A2 and B2, were downscaled with the Swedish regional climate model RCAO (R) (Rummukainen *et al.,* 2001). These scenarios are referred to as RH A2/B2 and RE A2/B2. Changes in the design precipitation due to climate change were treated separately since the design precipitation is an extreme event and will therefore probably change differently compared to average precipitations. We evaluated climate change effects on the design precipitation using the report from the Finnish Meteorological Institute (FMI) (Tuomenvirta *et al.,* 2000), which utilises results for 2070-2099 from the HadCM2 model with an emission scenario IS92a. The average increase in 1/5 and 1/15 year 14 day precipitation was evaluated from this report and was 20-29 % depending on the time of year. The hydrograph used in this study was derived from an actual high flow situation and scaled such that each historical high flow event observation was simply multiplied by the ratio of maximum discharge of 1/250 year RE A2 scenario and the maximum discharge in the historical dataset.

Secondly, hydraulic modelling was undertaken with HEC-RAS, a one-dimensional hydraulic model for steady and unsteady flow situations in a channel network. Unsteady computation is based on the conservation of mass and momentum and solved with Saint-Venant equations by the method of implicit finite difference. Structures such as storage areas, pump stations, bridges, culverts, weirs and embankments may be included in the model. The total length of reaches is approximately 50 km, of which the two main reaches comprise 33 km. The model geometry consisted of 28 separate reaches that were connected by 18 junctions. The number of individual cross sections (491) was obtained by GPS connected to an onboard MD 300 echo sounder system. After processing the raw scan data which included rectification of the scanning lines precisely perpendicular to flow direction, each cross section comprised an average of 25 representative underwater points. The mean distance between the cross sections was 92 m with a variance of 59 m. Floodplains were added as they were represented in a municipal and national elevation database. Municipal elevations were equivalent to 2x2 m DEM and national elevations to 10x10 m DEM. Embankments were added in the model geometry as they were presented in the preliminary blueprints for the restoration project. The model was calibrated against three thaw period high flow situations, which in this study were considered to date between May and October. Though discharge and water elevation observations have existed since the early 20th century in the Environmental Information System HERTTA, only data from the 1980's were deemed relevant due to dredging and other flow control activities in the river downstream. The average discharge in the approximately three week long calibration sets was 471 m^3/s with a minimum flow of 138 m^3/s and maximum flow of 724 m^3/s. Downstream boundary conditions for these sets were obtained from the Finnish Marine Research Centre and varied between level N60 -0.48 … +0.19 meter. The calculated water elevations matched Lukkarisanta observation station to within a couple of centimetres.

Thirdly, water elevation data of the unsteady flow calculation for the rising stage of the future 1/250a flood (10 days) was imported to the GIS software (Arc-GIS 9.2). Water elevation calculations of the HEC-RAS model along the reaches of the Kokemäenjoki River were interpolated onto the raster surface. Water surfaces were merged to the raster DEM. As a result, flood expansion with water depth (flood hazard map set) was estimated for these 9 days. The overlay analysis of the flood inundation and buildings were undertaken in Pori city area. The flood hazard map set was analysed against the spatial database of the buildings (*fin.* RHR, hosted by Population Register Centre). This database includes information about location, usage, size of the building, number of floors and year of construction. By coupling the flood hazard map set (map by map) to the RHR database, potential flood damages to the buildings could be estimated during the rising stage of a potential future 1/250a flood.

RESULTS

Under present climatic conditions the simulated 1/100a and 1/250a floods in Pori were spring floods caused by a combination of snow melt and precipitation. In the conditions of 2071-2100, the 1/100a and 1/250a floods were autumn floods caused by heavy prolonged precipitation. In the simulations, the floods increased 3-24 % by 2071-2100 depending on the climate scenario (Table 1).

The hydrograph used in this study was derived from an actual high flow situation that took place in April and May 1970. The maximum discharge from the Harjavalta hydroelectric power plant (706 m³/s) reflected the discharge rate of 740 m³/s, in the city of Pori, when the original discharge is weighted by the increase of the watershed area from Harjavalta to Pori. Although this was not the maximum observed flow situation during a thaw period, it was among the highest and the hydrograph shows a single discharge peak. Each historically high flow event observation was simply multiplied by the ratio of maximum discharge of the 1/250a RE A2 scenario and the maximum discharge in the historical dataset (Fig. 1). Discharges at both the beginning and end of each scenario were set at *ca.* 200 m³/s. The downstream boundary condition was set to a steady level of N60+1.40 metres, which is very exceptional situation according to observations made by Finnish Marine Institute.

Table 1. The future discharges in Kokemäenjoki River, Pori. Climate data (HadAM3H & ECHAM4/OPYC3 scenarios with A2 & B2 emission scenarios) was down-scaled with the Swedish regional climate model RCAO. The highest discharge, RE A2 scenario was used in this study (in bold).

	1/100a flood (m3/s)	**Increase**	**1/250a flood (m3/s)**	**Increase**
Present-day flood	1140		1242	
2071-2100: RH A2	1173	+ 3 %	1274	+ 3 %
2071-2100: RH B2	1225	+ 7 %	1344	+ 8 %
2071-2100: RE A2	1398	+ 23 %	**1537**	**+ 24 %**
2071-2100: RE B2	1372	+ 20 %	1514	+ 22 %

During the first flood day with a discharge rate of 800 m^3/s, 2900 buildings were inundated in the simulation (figure 2). Most were detached houses (*ca.* 1300), followed by outbuildings (600). Spatially, the flood covered the floodplains both downstream and mid-reaches west from the main channel. The most hazardous flooding area was on the eastern side of the main channel in the residential area of Pormestarinluoto.

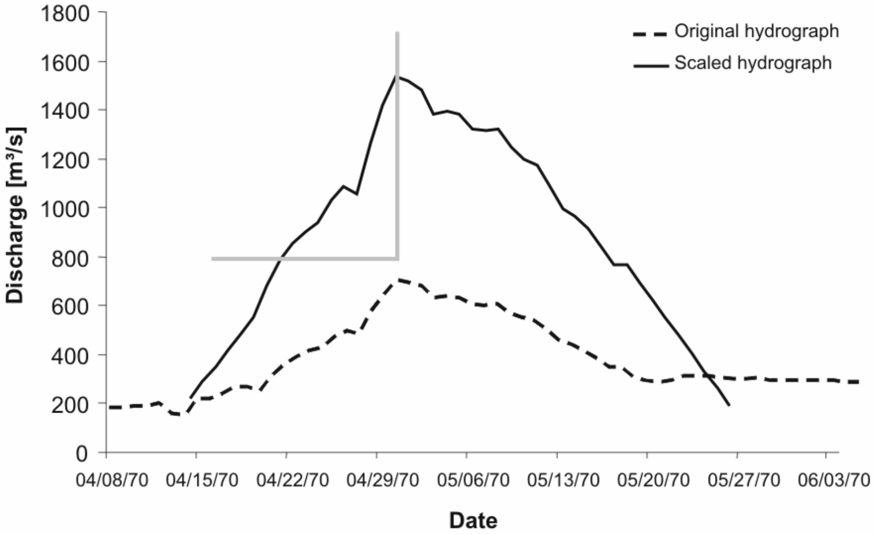

Figure 1. The scaled hydrograph used in this study. Ten days period starting from discharge 800 m^3/s was selected in the flood damage estimation (marked with grey line).

Furthermore, 14 other types of buildings were inundated during the first flooding day alone. Over the subsequent flooding days, approximately 300 new buildings were inundated every day. At the peak discharge stage (1537 m^3/s), *ca.* 6900 buildings were inundated including 3200 detached houses, 2 shopping malls, 242 apartment houses and 375 summer cottages. In addition to previously inundated areas, the flooding expanded into the other residential area further upstream as well as the industrial area located east of the city centre.

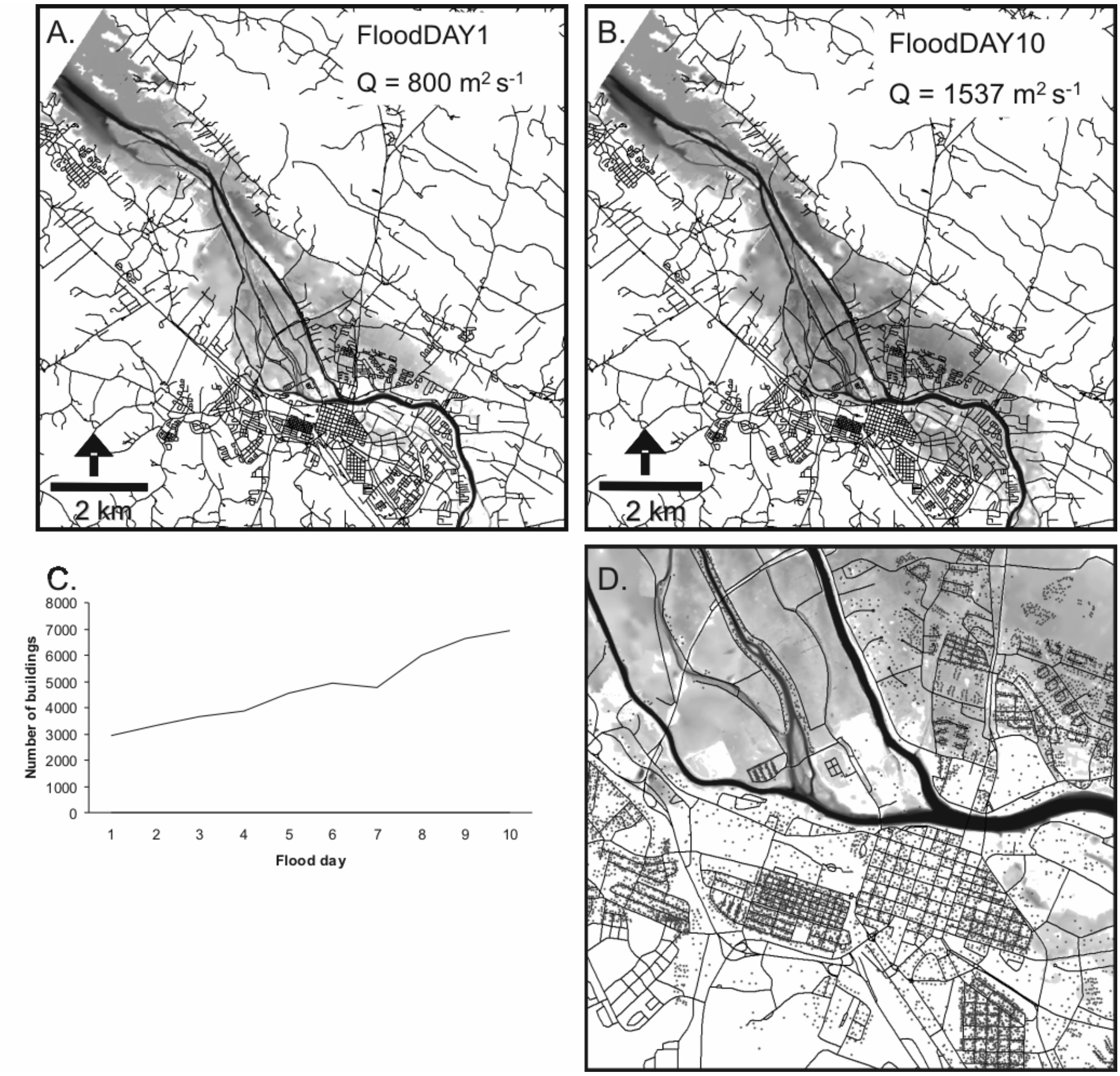

Figure 2. (a) Inundated area in the city of Pori in the first flood day in simulation. (b) Inundated area in the city of Pori during the peak discharge stage (day 10) in simulation (c) Number of the inundated buildings in flood day 1-10. (d) Example of overlay analysis with flood hazard map of flood day 10 and RHR database in the Pori city centre. Grey dots represents buildings, black lines are roads, black areas highlights river channel and inundation areas are marked with light grey.

CONCLUSIONS & FURTHER RESEARCH

The approach demonstrated in this study clearly shows an effective approach to flood risk mapping. The coupling of hydrological simulation using WSFS with unsteady one dimensional modelling offered a sensible estimate of a potential 1/250 flood inundation in the city of Pori. The flood hazard map set provided flood extension data during the rising stage of the potential future flood event. Overlay analysis enabled the accurate day by day estimation of inundated buildings during the flood event.

However, a few inaccuracies remain unsolved. Firstly, the method used in this study exposes the problem of one dimensional model when the flow in the scenario is dynamic and theoretical propagation over the embankments should occur. A more realistic approach would be to either take separate scenarios for each breach location where the propagation was modelled via separate reaches on the flood plain, or with a 2-dimensional modelling method. Secondly, sedimentation and land uplift effect was not taken into account. Thirdly, the factor of urban growth in the built up areas of Pori city was not considered at this stage of the study. Thus, it should be noted that GIS analysis gives only minimum damage estimation, due to the lack of the RHR data manipulation. Finally, we should bear in mind that embankments were considered to bear the flow velocity and that they were distinctly higher than the water elevation in the channel. However, the inundated areas were represented as theoretical flood areas without the protection of embankments. In a real embankment breach situation, the most vulnerable part of study area could be divided into five segments which are delineated for example by railroad and road embankments. It is the authors' aim to solve all of these inaccuracies with future research.

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Managing the challenges of climate change and impacts of hydrological change on hydro power production from the water resources of the Volta lake in Ghana – A case study

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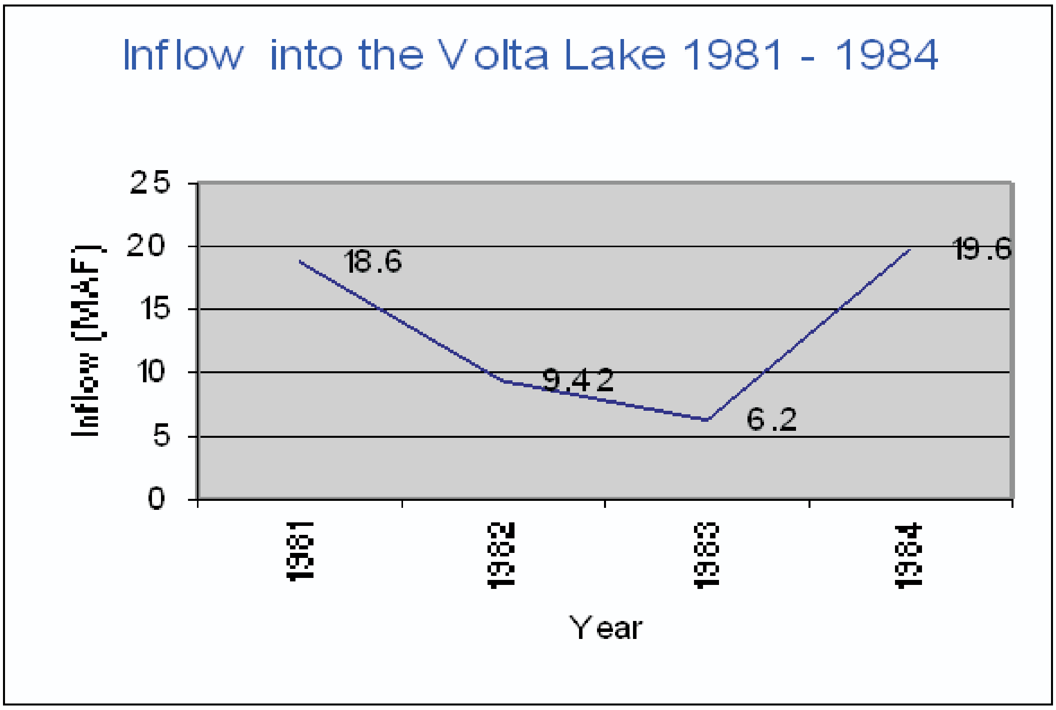
Key Words: Water resources, Climate and Hydrological change, Mitigation of impacts, Interventions, Water availability, Minimisation of Environmental effects and Social impacts, Achievements and Shortfalls.

The Volta River Authority (VRA) in Ghana was established under the Volta River Development Act 1961 (Act 46) with the primary function of generating electric power, first by the development of the hydroelectric potential of the Volta River for the supply of electrical energy for industrial, commercial and domestic use in Ghana. The Akosombo Dam/Hydroelectric Plant was therefore constructed and commissioned in 1965 to fulfil this legal mandate by generating power utilizing the water resources of the resultant Volta Lake. The Volta Lake has a surface area of about 8500 km2, an average depth of 18.8m and a shoreline of about 5,500 km. The total volume of the reservoir at full supply level of about 84.73 m is approximately 150 billion m3. To ensure greater use of the outflow water from the Akosombo Hydroelectric Plant, the Kpong Hydroelectric Plant (160MW) was constructed and commissioned in 1982 to enable the capture and reuse of water that would have flowed into the sea.
VRA operates a total installed electricity capacity of 1,180MW from the two hydroelectric power plants made up of 1,020MW and 160MW hydro from the Akosombo and Kpong Generating Stations, respectively.

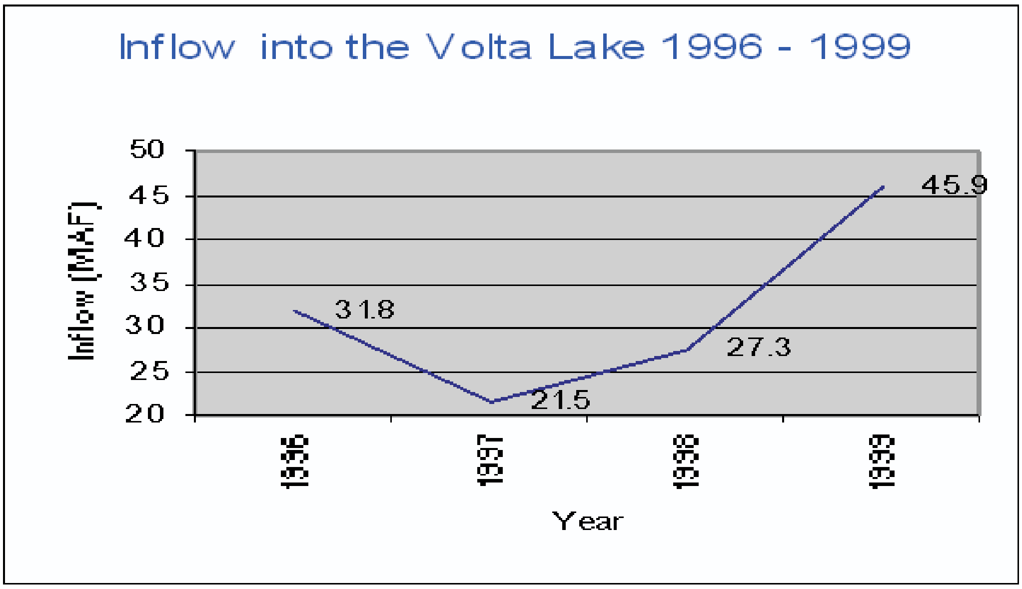
In the spirit of Regional Cooperation in the ECOWAS sub region, the VRA transmission system is interconnected with those of Ghana's neighbouring countries La Cote d'Ivoire, Togo/Benin and Burkina Faso. Hence any impact due to climate or hydrological change on the hydroelectric generating capability of the VRA constitutes a direct threat to industrial development in all the adjacent or neighbouring countries as well.

The Volta Basin has a climate controlled by three air masses: the south-westerlies or the monsoons which originate in the sub-tropical anticyclone of the South Atlantic; the north-easterlies or the harmattan which originate from Sahara High; and the equatorial air-masses which is restricted within latitudes 5° and 14° N. In January or early February, the Volta Lake lies wholly in the harmattan air-mass; the weather is then dry and warm during the day and cool during the night. The chance of rainfall during this period is very small. However, in recent years, climatic changes have occurred leading to an earlier inception of the harmattan, and a reduction in the rainfall quantum as well as its pattern in the country which could be attributable to climate change and global warming. The hitherto dry season of January – February has significantly changed to October - February. These changes have resulted in continuous decline in the water inflow into the Volta Lake. The lowest headwater elevation experienced in the system (235.76 feet) occurred in 1984 (11th June), a clear impact of the serious climatic challenge in the form of drought or low rainfall that occurred in the previous year 1983. Last year, inflows into the Akosombo Reservoir were below expectation. As at August 1, 2006, the elevation of the Lake was about 236.99 feet, the lowest level ever experienced for this time of the year. Ghana is therefore currently experiencing serious energy crisis.

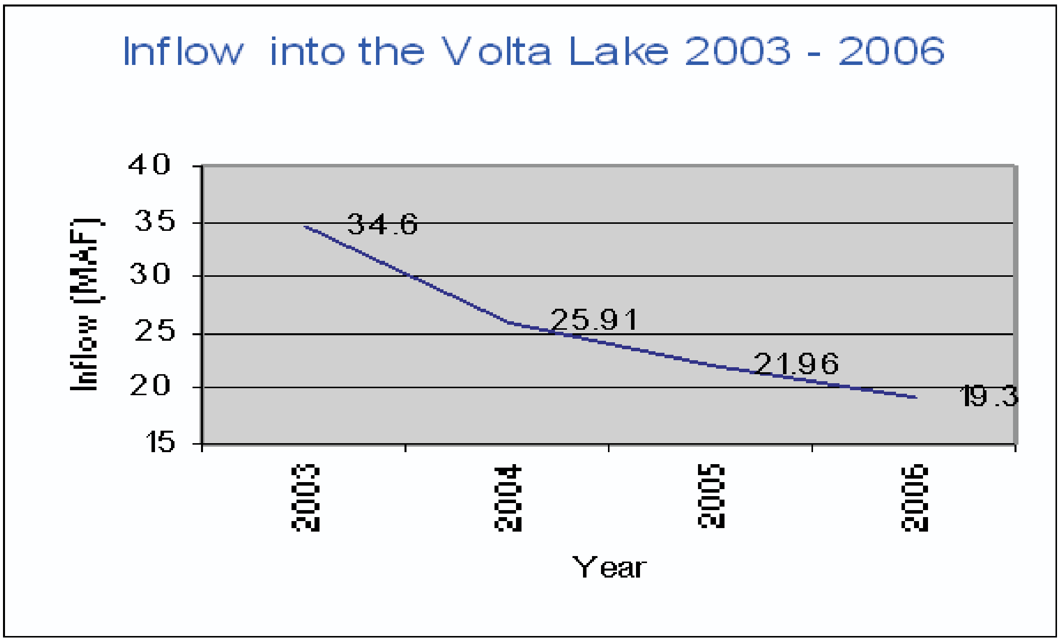
The following graphs portray the stark correlation between the low rainfall and dwindling inflow (MAF = Million Acre Feet) into the Volta Lake and the years of drought experienced in Ghana.



Low rainfall and dwindling inflow 1981-1983, led to energy crisis in 1984



Decreased inflow in 1997 resulted in energy crisis experienced in 1998



Reduced inflow in 2006, reduced hydropower generation, cause of current energy crisis in Ghana 2007

Power Generation and Water availability

Available statistics indicates a clear demonstration of the impact of climate and hydrological change on water availability and power generation; years of severe climatic challenges correspond to low water resource availability in the Volta Lake and low hydroelectricity generation.

Lake Transportation and Water availability

Due to the general north/south orientation, the Volta Lake serves as waterway for both large and small vessels. The lake transport service provides a convenient and cheaper means of moving industrial and constructional materials as well as petroleum products, and this has been found to be 60% less expensive than overland transport of goods. However, when the water level gets below the 79.0m mark the north-south water transport system is disrupted. Transport services are therefore suspended resulting in great loss of revenue.

INTERVENTIONS BY VRA AND OTHER STAKEHOLDERS FOR WATER MANAGEMENT

In order to mitigate the impacts of climate and hydrological change on the water resources of the lake, the VRA initiated and implemented various projects which seek to reverse the impacts, ensure availability of water, minimise environmental effects of the formation of the Volta Lake. Projects include research and development work pertaining to fisheries, the hydro-biology of the lake, public health, shoreline agriculture and community improvement projects. Project themes include:

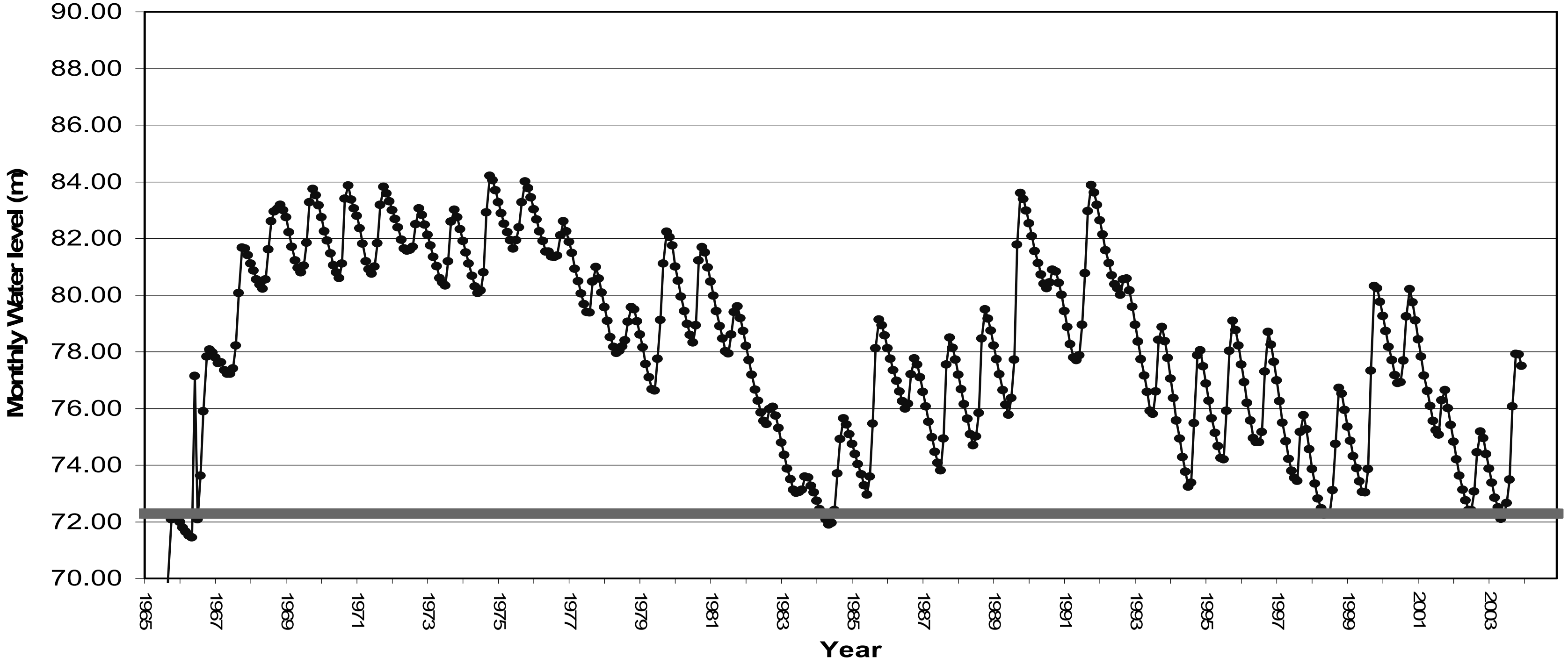
Creation of forest reserves to serve as water conservation areas that would help conserve water in the Lake. In all, about 22 forest reserves have been created in the Volta Basin located within 1 kilometre radius of the Volta Lake waters.

Reforestation Projects to conserve water in the lake.

Management of growth of water weeds which deplete lake water through evapo-transpiration and

Biodiversity Conservation

Table : Water levels of the Volta Reservoir at Akosombo – 1965 to 2003



Source: Volta River Authority, Ghana; (Engineering Services Department)

APPENDIX A Statistical Information on VRA funded Volta Lake Protection Projects, Objectives, Costs and Donors

Management Issue	Project Title	Objectives / Other Details of Project	Period	Donors	Amount	Implementing Agency	Stakeholders	Remarks
Reforestation to protect catchment area	Volta Gorge Reforestation Project	Aimed at protecting 7,000 hectares on either banks of the lake from Akosombo to Dodi Asantekrom	1994-2004	VRA	¢2.823 billion	VRA/Forestry Commission	VRA	Area around the dam is forested, bush fires prevented.
Preventing Deforestation	Tree cover depletion minimization at Yeji on Volta Lake	Aimed at restoring 1422 acres of tree cover and minimise rate of depletion of tree resources by 60% through agro forestry at Yeji	1995-2003	VRA	US$299,391 + ¢76,565,000	VRA/Department of Fisheries	Local communities engaged in fishing	Restored tree cover and provides fuelwood
Management of Water Weeds	Integrated management of water hyacinth on the Lake Volta	Use of chemical, physical and biological methods to control the spread of water hyacinth	2000-2002	VRA	¢170million	VRA	VRA	Removal of Water Hyacinth on the River Oti arm of Volta Lake
Environmental Management	Dredging at Volta estuary(Lower Volta)	Use of suction dredger to dredge sandbars and salt water channels in river	1989-2004	VRA	$1,740,808 + ¢13,2 billion	VRA	VRA District Assemblies at lower Volta basin	Improvement in salinity at estuary leading to more effective control of bilhazias
Preventing Deforestation	Environmental Degradation in the Volta Gorge North of Akosombo Dam: Dimensions and Recommended Mitigative Measures	Investigated and recommended mitigative measures for halting deforestation in the gorge area within the neighbourhood of Akosombo	1998	VRA		Volta Basin Research PRoject	VRA/Ministry of Environment and Science	Study recommended the delineation of a zone prohibited to settle, intensification of efforts at sustainable management strategies within the critical gorge area, resettlement of affected population within the prohibited zone and introduction

Management Issue	**Project Title**	**Objectives / Other Details of Project**	**Period**	**Donors**	**Amount**	**Implementing Agency**	**Stakeholders**	**Remarks**
								of livelihood support programmes in the affected area.
Lake Sedimentation	VRA Engineering Design and Construction: Sedimentation Study on Volta Lake	Sedimentation study on the Volta Lake covering area from the Akosombo dam to an approximate distance of 2 km upstream. Study was aimed at providing documentation on the extent of sedimentation in the lake	March 1995 to March 1996	VRA	¢32,316,936	Bidex Consult, Accra	VRA & other water users of the Volta Lake.	The study revealed occurrence of significant sedimentation, and recommended a more extensive and comprehensive study that would provide a framework for sustainable management of the problem.
Lake Sedimentation	Debre Shoals Dredging Project	Dredging bottom sediments to improve lake transport	Feb. 2001- January2003	Dutch Govt' VRA	15.43 million Dutch Guilders	VRA	VLTC Local Communities	Facilitate transport of goods to the North
Landslides in Volta basin/Lake Sedimentation	Study into the causes and recommendations for remedial measures for landslides along the shoreline of the Volta lake	In-depth investigation into pertinent socio-economic factors impinging on slope instability problem along critical sections of the Volta lake shores with a view to evolving strategies for minimising the chances of occurrence	March 1994 - March 1995	VRA	¢26,514,904.30	Conterra Limited	VRA ; District Assembly & communities within the Volta Gorge area.	Recommended active involvement of various interest groups, including target population in the formulation, execution and management of the identified regulatory mechanisms and education of target population establishment of a Land Resource Management Programme

Dam safety in a climate change perspective

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Keywords: dam safety, climate change, design floods.

ABSTRACT

The sensitivity to a future changed climate of the Swedish hydrological dam safety guidelines for calculations of design floods for dam constructions have been studied on behalf of Elforsk and the Swedish Dam Safety Authority (Svenska Kraftnät). Design flood calculations for five Swedish high hazard dams (riskklass I) have been analysed. The calculations were based on four regional climate scenarios from Rossby Centre corresponding to the time period 2071-2100.
The strategy was, as far as possible, to redo the analysis that was done in the original work on the Dam Safety Guidelines, however valid for a changed climate according to the different scenarios of the future climate. Some summarizing conclusions are:

- Design inflows and water levels are affected by a changed climate.
- Changes in the mean climate results in smaller design snow pack according to all scenarios. This component acts towards decreased design inflows and water levels at most locations.
- Extreme precipitation can be expected to increase at most places in Sweden according to the scenarios. This component acts towards increased design inflows and water levels at most locations.
- Depending on how changes in the mean climate and in the extremes interact, the change in design inflows and water levels can be either an increase or a decrease depending on location and choice of scenario.

The uncertainties that were revealed in this study underlines the need for further studies on how design flood calculations are affected by changes in future climate. The work on these questions will continue within a new national project "Design floods for dams in a changing climate – Scenarios in a 50-year perspective" financed by Elforsk and the Swedish Dam Safety Authority, and also within the new Nordic Energy Research funded Climate and Energy Systems project (CES).

INTRODUCTION

Since 1990 new guidelines for hydrological design of the Swedish hydropower system are being implemented (Flödeskommittén, 1990). The technique is based on a critical combination of extreme precipitation, extreme snowmelt and an operation strategy for multi-reservoir systems. Hydrological modelling is a central component, as is a prescribed design precipitation sequence. At the time when the guidelines were developed it was not possible to account for possible consequences of a changing climate. This has, however, been considered a potential threat in the light of recent development of the climate issue. The precipitation over Sweden 1991-2005 increased by about 7% if compared to the current reference period 1961-1990 (SMHI, 2006). The corresponding change in annual mean temperature was about + 0.9°C.

To evaluate the sensitivity of high hazard dams in Sweden to climate change, analyses was initially done for four important Swedish dams and also for the largest lake in Sweden, Lake Vänern (Andréasson et. al., 2006). In an additional study, financed by Elforsk and the Swedish Comission on Climate and Vulnerability, calculations were done also for River Umeälven (Pengfors) (Andréasson et. al., 2007). In that study the focus was broaden to also include analyses of possible changes from climate change in the 100-year flood in a regulated river system. The 100-year flood is important for dam safety since it is used in the design calculation of low hazard dams. All test basins are shown in Figure 1a.

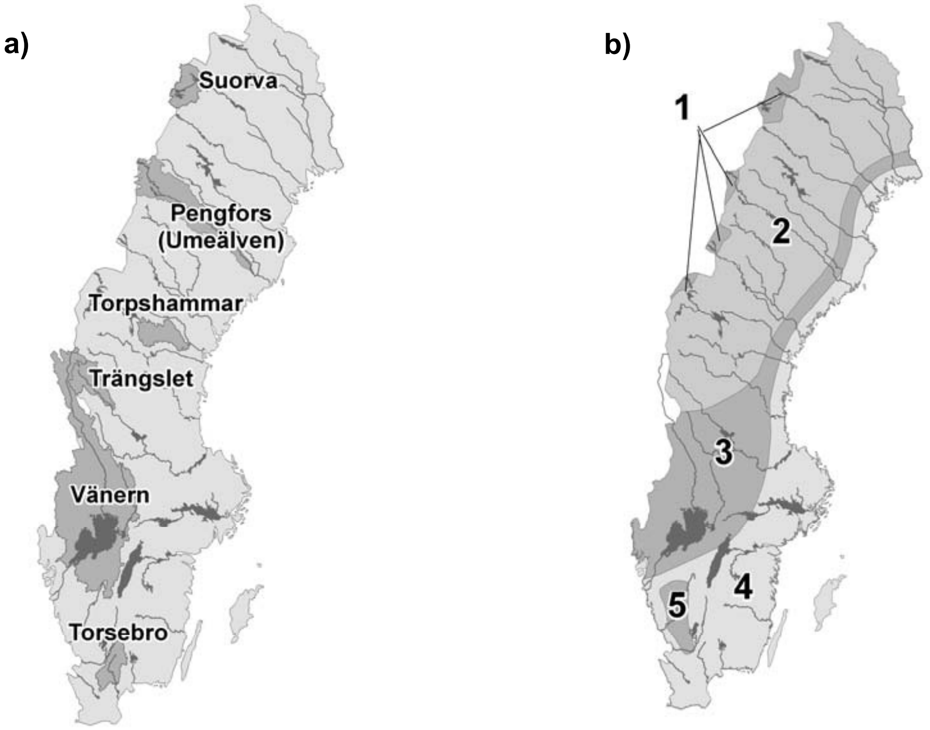

Figure 1. a) Test basins used for evaluation of dam safety in a changed climate and b) regions for design precipitation sequences.

THE KEY QUESTIONS ASKED

Calculation of design floods for a changed climate can be summarized by the following four key questions:

- How much wetter or dryer will the future mean climate be according to the climate scenarios?
- How will the conditions for having a large snow pack change according to the climate scenarios?
- How will climate change effect extreme precipitation, i.e. the design precipitation sequence?
- How will these changes act together on the design floods and the design water levels?

METHODS

No changes in the methodology to calculate design floods as described in the Swedish dam safety guidelines from 1990 have been made, except from adjustments to a climate as suggested by regional climate scenarios. The sensitivity analysis was based on four different regional climate scenarios from the Rossby Centre Regional Atmosphere-Ocean (RCAO) model (Döscher et al., 2002). The RCAO model was forced by boundary conditions from two Global Climate Models, HadAM3H (Gordon et al., 2000) and ECHAM4/OPYC3 (Roeckner et al., 1999), and two emission scenarios, SRES A2 and B2 (Nakićenović, et al., 2000). The scenarios correspond to the time period 2071-2100.

Hydrological simulations were carried out with the conceptual HBV model (Lindström et al., 1997). Transfer of the climate scenarios to the hydrological simulations was done using the so-called delta change approach (c.f. Andréasson et al., 2004).

In the guidelines, Sweden is divided into five regions which all have different prescribed 14-days design precipitation sequences (Figure 1b). After frequency analysis (Gumbel distribution) of the climate model precipitation, new design precipitation sequences were constructed for each of these regions.

In addition to the design precipitation sequence, the snow storage was lifted to the 30-year level before the spring snowmelt and the soil moisture deficit was set to zero, i.e. saturated soil. New snow levels were calculated using scenario climate data as input to the impact simulations.

Calculation of the change in 100-year flood in River Umeälven was done from hydrological simulations using observed input (present climate) and climate scenario data together with the delta change approach. The regulation strategy in the climate change simulations (2071-2100) was adjusted so that the filling-up phase of the reservoirs started 4-6 weeks earlier in the most important reservoirs. This was necessary to avoid unrealistic conditions caused by earlier spring flood in the climate impact simulations.

RESULTS

All four regional climate scenarios resulted in increased annual runoff volumes in all testbasins, except from the HadAM3H scenarios in Torsebro (Table 1). The seasonal distribution of runoff was in its shape similar as for present climate in the northern basins, although the spring flood was smaller and 2-4 weeks earlier in the scenarios (Suorva, Torpshammar and Trängslet). The less stable winter conditions also resulted in higher autumn and winter runoff due to intermittently snow melt (Figure 2a). In the more southern basins, Vänern and Torsebro, the characteristics of the present seasonal distribution of runoff were enhanced in the climate impact simulations. The already high winter and spring runoff were increased while the low runoff during summer decreased (Figure 2b).

Table 1. Change in mean annual inflow (%), 1961-1990 vs. 2071-2100, according to the four regional climate scenarios.

	Suorva	Torps-hammar	Trängslet	Pengfors	Vänern	Torsebro
RCAO-H/A2	+12	+9	+13	+7	+1	-6
RCAO-H/B2	+8	+10	+12	+4	+3	-2
RCAO-E/A2	+53	+22	+18	+36	+22	+17
RCAO-E/B2	+35	+17	+15	+22	+16	+12

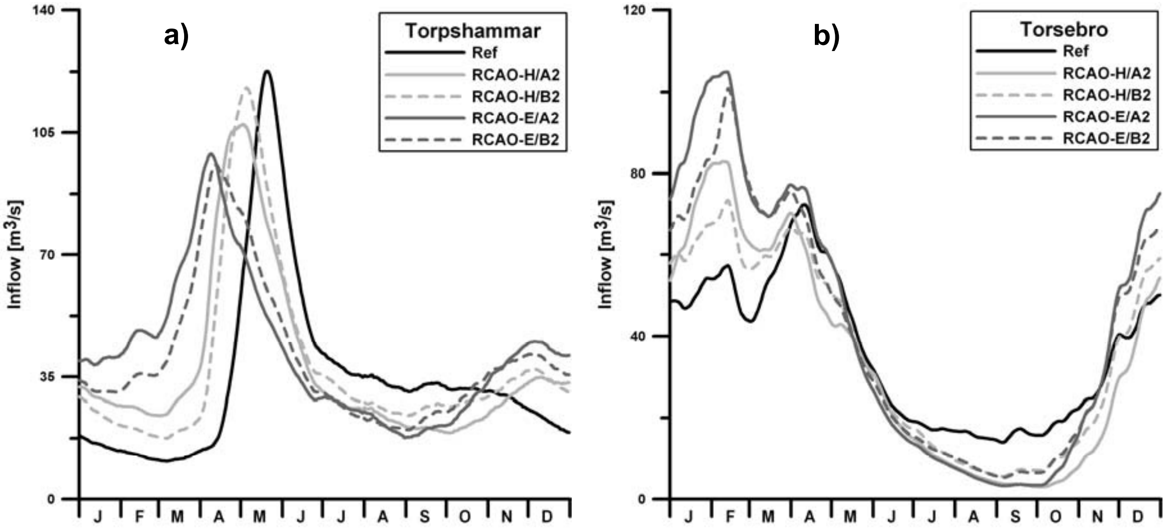

Figure 2. a) The seasonal dynamics of mean annual inflow in Torpshammar, a typical northern basin. Ref corresponds to 1961-1990 and the four climate impact simulations to 2071-2100. b) The same as in a) but for Torsebro, a typical southern basin.

In all test basins and for all scenarios, the calculated 30-year snow storage decreased when using delta change perturbed precipitation and temperature as input to the simulations. The decrease was especially large in the southernmost basin Torsebro, where the maximum snow storage in some scenarios was as low as 30 percent of the snow storage for the present climate. The change in snow water equivalent was however much larger in the north where the snow storage is larger.

The total volume as well as the peak value of the scenario design precipitation sequences increased for most of the scenarios and regions (Table 2).

Table 2. Changes in the design precipitation sequences for each region (%). The left column is the change in total volume and the right column is the change in maximum precipitation.

	Region 1		Region 2		Region 3		Region 4		Region 5	
RCAO-H/A2	-6	+15	+3	+19	+30	+33	+18	+30	+3	+19
RCAO-H/B2	0	-6	+5	+4	+10	0	-1	+17	-1	-11
RCAO-E/A2	+41	+40	+35	+26	+14	+31	+14	+5	+54	+4
RCAO-E/B2	+46	+7	+35	+17	+9	+21	+1	+25	+29	-4

With the use of changed background climate, modified design precipitation and 30-year snow storage of the scenarios, new design floods corresponding to the scenario conditions were calculated (Table 3). Changes in design water levels were calculated for three of the test basins (Table 3). Sensitivity simulations using the changed background climate but together with the original design precipitation were also performed to find out the impacts from each component in the calculations.

Table 3. Changes in calculated design peak floods according to four climate change scenarios in the five test basins (%). Corresponding changes in design water levels are within brackets (m).

	Suorva	Torpshammar	Trängslet	Pengfors	Vänern	Torsebro
RCAO-H/A2	-9	-3 (-1.4)	+14 (+0.4)	+1	+16 (+0.5)	-8
RCAO-H/B2	-6	0 (-0.2)	+9 (+0.2)	+1	-5 (+0.1)	-19
RCAO-E/A2	+20	-3 (-1.3	-14 (-0.3)	+19	+13 (+1.0)	-10
RCAO-E/B2	+16	-1 (-0.4)	+1 (+0.7)	+17	+6 (+0.7)	-22

The frequency analysis on simulations in the regulated River Umeälven (Pengfors) showed that simulations based on scenarios from RCAO-ECHAM4/OPYC3 resulted in an increase of the 100-year flood of between +14 to +35 %. The changes were smaller for the simulations based on RCAO-HadAM3H, between ±0 to +7%.

DISCUSSION AND CONCLUSIONS

The sensitivity of the Swedish dam safety guidelines to a changed climate has been evaluated using four different regional climate scenarios for six locations in Sweden. The calculated design floods and water levels have been found to be sensitive to a changed climate.

In general, the analysis of scenario precipitation indicates an increase in extreme precipitation for most parts of Sweden. The maximum snow storage (30-year level) that is used in the design calculations decreased in all scenarios. It is very difficult to beforehand determine whether the change in design levels will be an increase or a decrease due to the complex combination of snow storage and precipitation used in the calculations. The calculated design floods and water levels both increased and decreased depending on location and choice of scenario.

The analysis of changes in the 100-year flood that was done in River Umeälven (Pengfors) showed that the 100-year flood will increase according to the scenarios. The future 100-year flood will occur at different time of the year than in present climate, due to smaller spring floods. The result should therefore be treated with caution, since changes of the hydrological regime probably will have large impact on the regulation strategy. In this analysis it was only possible to adjust the regulation strategy regarding the start of the filling-up phase and not for the rest of the year.

Some summarizing conclusions are:

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ACKNOWLEDGEMENT

The work in this paper was financed by Elforsk, the Swedish dam safety authority (Svenska Kraftnät), the Swedish Comission on Climate and Vulnerability and the Nordic Energy Research funded Climate and Energy project.

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Water Portfolio Management – global water stress adaptation examples

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Keywords: climate change, integrated water management, water reuse, potable substitution.

ABSTRACT

The climate is changing and water resources are affected by these changes. We are today confronted with a water scarcity problem that is predicted to grow with time. Water scarcity exists when the water demand is exceeding the water supply at a local level or the clean water resources are polluted by flood water. The quantity of available resource then depends on the evolution of the demand and the supply available locally.

The paper will introduce a new prospective in explaining that availability of global water resources depends on the appropriate treatment of wastewater to increase water availability by enhancing surface and groundwater resources so that the water can be reused through abstraction for agriculture, industry and treatment for potable use. One of the most significant developments in water management in recent years has been the increasing focus on integrated water supply planning, including water recycling and demand management. This allows different sources of water to be compared side-by-side with traditional infrastructure solutions. Recognition of the full water cycle means that often-overlooked options, such as storm water, are given equal opportunity to be assessed on their merits. This advance blurs the traditional boundaries between the supply of water, wastewater and storm water services to provide what is termed 'integrated water cycle management' or water portfolio management as a climate change adaptation solution.

Several examples will show that although river basin water management is being used to balance catchments with demand, it is difficult to implement regular water strategies in regions already impacted by water stress or where there are few rivers. The Australian and Chinese Governments have been promoting Integrated Water Cycle Management which recognises that water also recycles locally rather than just flowing down the river to the sea.

INTRODUCTION

The climate is changing and water resources are affected by these changes. We are today confronted with water scarcity problems in many areas that are predicted to grow with time (Stern 2006; IPCC 2007). Water scarcity exists when the water demand exceeds the water supply at a local level or when the clean water resources are polluted by flood water. Several reports (e.g. EEA 2007) show us that adaptation policies to face climate change are needed and that the water cycle is being intensified. Based on a comprehensive review[1] of academic papers the Stern Review even states that it will reinforce existing patterns of water scarcity and abundance and increasing the risk of droughts and floods (Stern 2007, p.2). For example, Southern Europe summer water availability may fall by 20%-30% due to a warming of 2°C that corresponds to a concentration of 450 ppm of CO_2 in the atmosphere and by 40%-50% due to a warming of 4°C (650 ppm). River flows in New South Wales in Australia are predicted to drop by 15% for a 1°C to 2°C rise in temperature.

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[1] See among others, Huntington, T.G. (2006): 'Evidence for intensification of the global water cycle: review and synthesis', Journal of Hydrology 319: pp. 1 – 13

In general, the hydrological cycle is expected to become enhanced as global temperatures increase (ECCP 2007, pp.2-3). For every degree Celsius of warming, the air can theoretically absorb 7% more water vapour. Climate models predict an increase in precipitation of approximately 3% for each degree increase in temperature. The expected impacts of climate change across Europe on the water cycle include the following:

- projections up to 2100 show precipitation increase in the North of Europe (mostly in winter) and decrease in summer precipitation in the South of Europe,
- extreme precipitation will occur more frequently, especially in winter, which may lead to more frequent flooding,
- in Central and Southern Europe, the drought risk is likely to increase,
- changes in precipitation patterns may alter the availability of surface water, which could lead to increased exploitation of groundwater resources,
- reduction of snow and ice cover in combination with higher potential evaporation may lead to earlier and decreased river discharge in spring and reduced downstream water availability in summer with an increased risk of flooding from collapsing ice dams,
- sea-level rise will affect fresh water resources in low-lying coastal areas by saline intrusion.

The quantity of available resource then depends on the evolution of the demand and the supply available locally. The evolution of the demand for water can be influenced by several parameters such as population growth, water needs for agriculture, or urbanization for example whereas the evolution of the supply is influenced by climate (and thus by climate change), by changes in water quality and by the competition between uses resulting in water stress.
Climate change is also having and will continue to have the greatest impact upon the lives of the poor in developing countries (Cabot Venton 2007). Most developing countries are in tropical or arid regions which will experience climate change sooner and on a greater magnitude than in temperate regions. This change will greatly compromise development spending and progress toward the achievement of the Millennium Development Goals for water and sanitation. Further, the poor tend to be more vulnerable to the impacts of climate change due to the location of the land they live in (floodplains, steep unstable slopes and exposed coastlines).

This paper will show that although the global stock of water does not change, water is not always available in sufficient quantity locally. We will then focus on water management practices in recent years in order to demonstrate that an increasing focus on integrated water supply planning, including water recycling and demand management has been tested and works. The paper will finally feature a direct adaptation experience on mass migration problem in Durban (South Africa) during the nineties where the implementation of a demand-side management policy protected public health and brought environmental sustainability of the water services in the region.

GLOBAL WATER CYCLE AND CLIMATE CHANGE

There is a finite amount of water on earth of which 2.5% is estimated to be freshwater and the remaining 97.5% is saltwater. Out of this total water stock, around 0.7% are freshwater located in groundwater, lakes and rivers. The global quantity of water does not change. What is important to focus on is the residence time of a molecule of water in different places such as aquifers, rivers, the sea, etc.

Figure 1 shows the world's water cycle with the estimated residence time of a water molecule in the atmosphere, in aquifers, in river channels, in oceans and seas, among others. It is important to recognise that freshwater entering the sea is lost to abstraction or beneficial use (whether potable or not). Indeed, freshwater discharging to the sea is no longer available without expensive desalination technology for approximately four thousand years. Freshwater in rivers stays approximately two weeks before reaching the sea and freshwater in lakes and reservoirs has a residence time of approximately ten years. It is therefore important to maximise our water availability before the freshwater reaches the sea.

Another study (Lorenz, Kasang & Lohmann 2007, pp. 157-161) argues that there is some evidence from paleoclimatic records and new modelling studies on recent global warming that climate change affects the global water budget which is linked to the availability of water. The authors conclude that the understanding of involved mechanisms and feedbacks is essential for the prediction of the future water cycle and to be able to predict future chain reactions of the global climate.

At a local level, the availability of the water resources depends on the appropriate treatment of wastewater to enhance surface and groundwater resources so that the water is available for abstraction for agriculture, industry and treatment for potable use. Many cities in the world already rely on indirect potable reuse for 70% of their potable resource during dry summer conditions due to high population density (Durham, Kim & Jeong 2005).

INTEGRATED WATER CYCLE MANAGEMENT PRACTICE AROUND THE WORLD

The Integrated Water Cycle Management (IWCM) approach that has been adopted in Australia and China is needed to avoid the risk of focusing separately on drinking water and wastewater management as if they are not part of the same local water management cycle. The IWCM approach must:

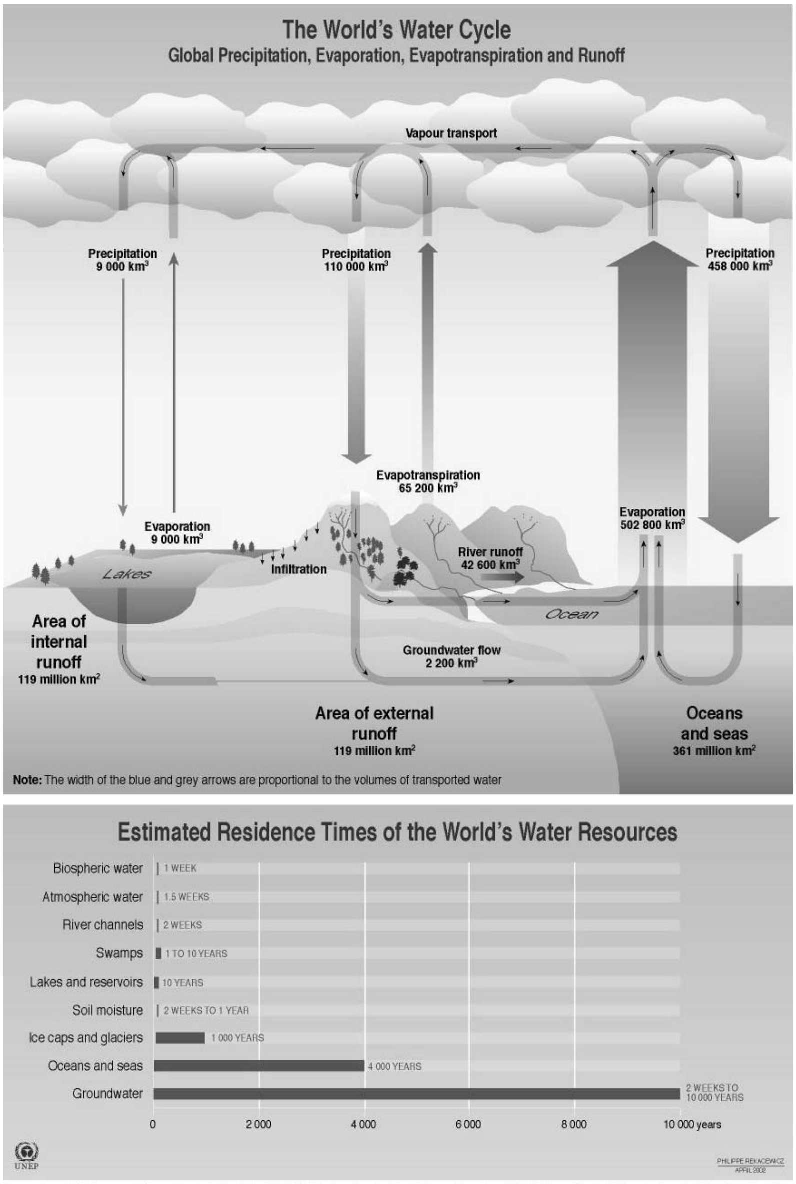
- Satisfy the appropriate quality standards and strive towards greater water security
- Meet today's needs without jeopardising the ability to meet the needs of future generations
- Enable the development of the local economy and satisfies local requirements.

Northern China is a water stressed region and the Government has reviewed and adopted best practice on water reuse from international experience and has resulted in:

- The adoption of an integrated water cycle management approach
- A reduction of the problems of overlapping institutions and regulation
- The implemented of demonstration projects to prove benefits and build local experience
- A policy that all types of wastewater treatment shall take reuse into consideration.

The Spanish government, through the A.G.U.A. (Actuaciones para la Gestión y la Utilización del Agua) program is considering systematic water reuse for irrigation and mobilization of other types of resource like desalination of saltwater in order to meet the growing needs of coastal population and respond to the new impacts of climate change happening in its territory.

River basin water management has been used to balance catchments with demand. However this is difficult to implement in arid regions where there are few rivers. The Australian and Chinese Governments have been promoting Integrated Water Cycle Management which recognises that water also recycles locally rather than just flowing down the river to the sea.



Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999; Max Planck, Institute for Meteorology, Hamburg, 1994; Freeze, Allen, John, Cherry, *Groundwater*, Prentice-Hall: Englewood Cliffs NJ, 1979.

Figure 1. : World's water cycle: schematic and residence time
Credit: Philippe Rekacewicz, UNEP/GRID-Arendal, downloaded from
http://maps.grida.no/go/graphic/world_s_water_cycle_schematic_and_residence_time

ADAPTATION PRACTICE: DEMAND-SIDE MANAGEMENT POLICY IN SOUTH AFRICA DURING THE NINETIES

Durban is a major port city in South Africa with a current population of about three million. While there are a number of upper class suburbs, most people live in townships of what could best be described as freestanding low-cost housing units. At least one million people live in informal peri-urban settlements.

The political scene changed dramatically during the nineties. South Africa had its first democratic election in 1994. The new constitution guaranteed everyone the right to a safe environment, and access to sufficient food and water. In order to realise these rights, a number of new laws were legislated. In 1989 the Group Areas Act was repealed. This cornerstone of Apartheid legislation determined where people could live and where they could not. With its repeal, available lands such as parks, close to work opportunities were occupied. The local authorities found it difficult to control, especially when the land belonged to the state.

By 1992 a large informal settlement of 3000 shacks had developed in Cato Crest, just 5 kilometres from the Durban city centre. The local water authority, Durban Water, on instruction from the city, installed a number of standpipes in the area to provide the settlement with a source of clean water. The original standpipes where mismanaged, with no control and excessive wastage. In order to manage the consumption and limit the wastage, a standpipe bailiff was introduced a short time after. The bailiff sold water in buckets to the community, and then paid the water authority for the water consumed at his metered connection. A 25 litre bucket sold for 10c€ or R4.00/kl. The bailiff purchased this water for R1.00/kl.

In 1993 Durban Water introduced the ground tank system in the settlement. This system, operating on prepayment, was developed to address the high cost of standpipe water, its unhygienic transport and storage, and the low level of service received. The ground tank provided each household with a 200 litre tank at their doorstep, which was filled daily by the bailiff at the cost of R10.00/month (R1.67/kl). The system proved to be very popular with almost 100% of households connected within a few years.

In 1995 Durban Water introduced an intermediate level of in-house water supply using roof tank storage. The new government had embarked on a rapid program of housing development for the poor and homeless. The roof tank system, together with waterborne sewerage, provided an acceptable level of water service but at a lower cost than conventional full pressure supply. The lower operating and maintenance costs of the reticulation were also passed on to the consumer through lower tariffs.

In 1997 it was found that the cost of administering the monthly billing and payments for the ground-tank system was higher than the cost of 200 litres of water consumed each day. A decision was taken by the city council to save these costs by providing water free to the ground tank consumers. A year later this free water allocation was extended to all domestic consumers in Durban by the introduction of a stepped tariff.

A spin-off of the decision to provide all domestic consumers in Durban with the first 200 litres free is that it gave the water authority the moral high ground when implementing disconnections for non-payment. Everyone received their constitutional right to sufficient water free, it was only when they used in excess of the 200 litres per day and refused to pay for it that they were disconnected.

The stepped tariff was based on the assumption that the average domestic household used 30 kl/month. The first 6 kl were free, as long as you did not exceed 6 kl for the month. When the consumer used more than 6 kl for the month they would be billed a fixed charge to cover the first 6 kl. The consumers, who used more than 30 kl would be charged at a penalty tariff for the excess consumption, thus cross subsidizing the free water consumed by “poorer” consumers. The stepped tariff, together with the various levels of service available, addressed the water supply needs of a city with vast differences in financial means and demands. In particular, the “free water” ensured that the water services were socially acceptable, whilst the stepped tariff ensured that the services were economically sustainable.

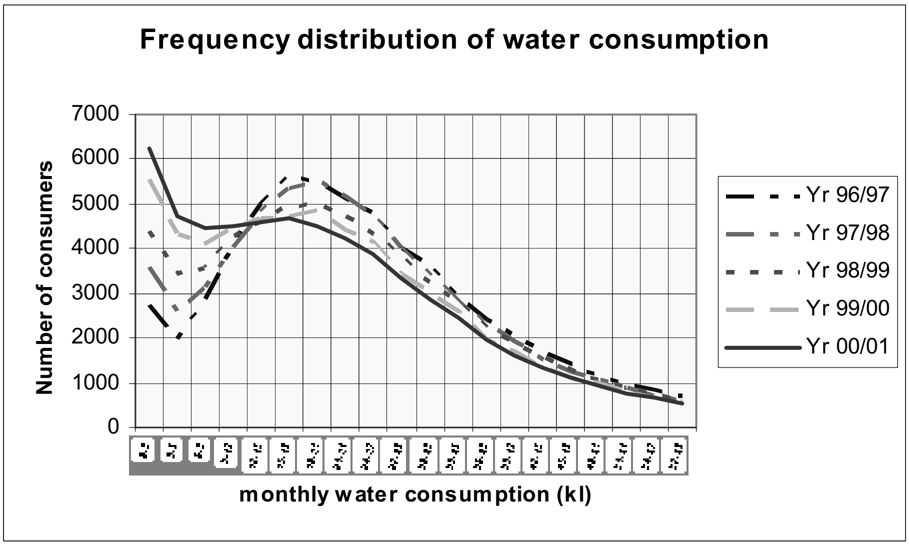


Figure 2: the stepped tariff structure in Durban

The stepped tariff also had a major impact on the environmental sustainability of water services in the region. The significance of the stepped tariff in reducing demand, as shown in figure 2 above is exposed in the frequency distribution below showing how consumers have adjusted their consumption since 1996, to avoid the penalty tariffs and take advantage of the free water allocation.
In addition, Durban Metro implemented since then a major reuse project so that treated wastewater (freshwater) that was being discharged to the sea was reused by industry instead of using potable water. This resulted in an 8% increase in potable availability and a direct benefit to the manufacturing industry. This is an excellent example of water reuse increasing water availability as a water scarcity solution.

DISCUSSION AND CONCLUSION

Best water management practice now emphasises a diversity of water sources in a portfolio selected not simply on least cost and timing, but also on the reduction in the covariance between sources. This is the concept of managing multiple water resources from storm water to seawater. Each resource has different availabilities, quantities, qualities and locations and can be tailored for different applications ranging from ecological management, cooling water, irrigation or potable production.
Figure 3 represents the possibilities offered by the portfolio management of available resources. It is a concrete example of a simple matrix showing the options a catchment has at his disposal in order either to slow down or to boost the natural water cycle when facing climate tensions.
One of the most significant developments in water management in recent years has been the increasing focus on integrated water supply planning, including water recycling and demand management. This allows different sources of water to be compared side-by-side with traditional infrastructure solutions. Recognition of the full water cycle means that often-overlooked options, such as storm water, are given equal opportunity to be assessed on their merits. This advance blurs the traditional boundaries between the supply of water, wastewater and storm water services to provide what is termed ‘integrated water cycle management’ or water portfolio management, a proven climate change adaptation solution.

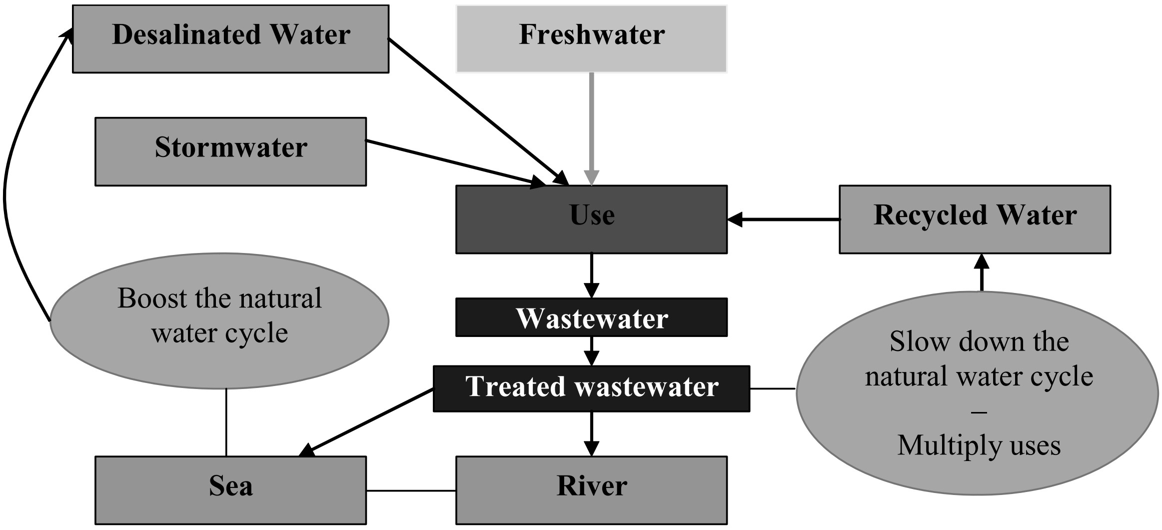


Figure 3: Portfolio management of water resources at local level

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Impacts of climate change on hydrological processes in the Nordic region

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Keywords: climate change, water resources, hydrological model

ABSTRACT

Climate change impact simulations for hydrological processes in the Nordic region for the period 2071-2100 have been estimated using results from global climate models from the Hadley Centre and the Max-Planck Institute, and dynamical downscaling using the Rossby Centre RCAO and RegClim HIRHAM regional climate models. These climate scenarios were used for driving the HBV and WaSim-ETH hydrological models. Present conditions were determined from control runs using observed meteorological data and climate model results for 1961-1990. Maps showing changes in annual runoff are presented. A moderate increase in annual runoff is expected in most parts of the Nordic region, with a decline in some parts for some scenarios. The changes depend on the spatial distribution of the atmospheric pressure fields as modelled by the two global climate models. Significant changes in the seasonal distribution of runoff are expected. Increase everywhere in the winter, increase in mountainous basins and inland basins in the spring, and a decline in coastal and southern basins in the spring. Decrease will occur everywhere in the summer, while autumn runoff will increase everywhere except in southern parts. The occurrence of large snowmelt floods is likely to become more seldom due to earlier snowmelt and reduced snow storage. The combined effect of increase in rainfall intensities, number of rainfall events and total rainfall volume will most likely provide conditions that may be expected to yield larger rain floods. Results from a study investigating the effects of changes in glacier covered area in a changed climate is presented.

INTRODUCTION

Assessment of the future hydrological regime is a production chain where changes in external forcing caused by greenhouse gas emissions are introduced into general circulation models and regional climate models. The climate model results are used for driving hydrological models which determine time series or statistics of hydrological state variables and fluxes for present and future climate conditions. Maps presenting spatial distributions of these statistics, e.g. annual or seasonal mean values and extremes are a useful way of communicating the results from modelling hydrological impacts of climate change. The results presented in this study have been produced by the Hydropower, Hydrological Models group of the Nordic research project Climate and Energy (CE). This project has the objective of a comprehensive assessment of the impacts of climate change on renewable energy sources in the Nordic countries, the Baltic States and Northwest Russia. The CE project was funded by the Nordic Energy Research, the Nordic energy sector and national institutions of the participating countries. Within the CE project a set of maps of water resources under present and future conditions based on climate scenarios and hydrological modelling techniques have been produced. These maps are based on four regional climate scenarios, resulting from two general circulation models, each forced with two greenhouse gas emission scenarios. Climate change scenarios differ substantially due to uncertainties with regard to the climate forcing caused by greenhouse gas emissions, uncertainties caused by imperfect representation of processes in the atmospheric models, and uncertainties with regard to initial conditions. Hydrological climate change maps which are based on ensembles of climate change simulations from model runs using different approaches to predict the future represent one way of quantifying this uncertainty. Climate change will have great influence on glaciers and streamflow from glacier fed rivers in Iceland and Scandinavia. A comparison was performed between climate change impacts on streamflow from two Norwegian catchments with the assumptions of (1) no change in glacier covered area compared to present conditions; and (2) glacier covered area is zero.

CLIMATE SCENARIOS AND HYDROLOGICAL SIMULATIONS

Results from the Max Planck Institute atmosphere-ocean general circulation model ECHAM4/OPYC3 (Roeckner et al., 1999), and from the general circulation model HadAM3H developed from the atmospheric component of the Hadley Centre atmosphere-ocean general circulation model HadCM3 (Gordon et al., 2000) have been used for assessment of climate change impacts on water resources in the Nordic countries. Assumptions about future greenhouse gas emissions were based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) A2 and B2 scenarios. The general circulation model simulations were used as boundary conditions for dynamical downscaling with two regional climate models: the Rossby Centre Regional Atmosphere-Ocean (RCAO) model (Döscher et al., 2002) and the HIRHAM model (Bjørge et al., 2000).

Hydrological simulations representing a slice of time in the present climate (control) and in a future climate (scenarios) were performed. The time slice for the control climate was 1961-1990 and for the scenario climate 2071-2100. The hydrological impact studies were done with off-line simulations with the hydrological models. The maps showing changes in annual runoff used observed meteorological data as a control climate in all countries, with the exception of Iceland where observed data were replaced by results from the MM5 atmospheric model at spatial resolution 8 by 8 km^2 (Grell et al., 1994). Changes in meteorological variables between the control and the scenario simulations from the regional climate models were transferred to a database of meteorological data. This can be referred to as the delta change approach, e.g. Hay et al. (2000) and is a common method of transferring the signal of climate change from climate models to hydrological models. Monthly relative precipitation changes and absolute temperature changes predicted by the regional climate models were used to modify the daily meteorological data driving the hydrological models for the baseline period 1961-1990. The same relative precipitation changes were used for extreme values as well as for average conditions, and the number of precipitation days was not changed in the scenario climate. A dynamical glacier model was used for modelling changes in the extent of Icelandic glaciers for the scenario period (Jóhannesson et al., 2006), whereas changes in glacier covered areas was not considered for Scandinavian glaciers. The sensitivity study investigating the effects of changes in glacier covered area from the present to the future climate transferred RegClim HIRHAM model results to meteorological station sites using an empirical adjustment technique which preserves the frequency of precipitation and temperature events as predicted by the climate models, aiming at reproducing observed monthly means and standard deviations for the control period (Engen-Skaugen, 2007).

Hydrological simulations were performed on a daily time step with the HBV model (c.f. Lindström et al., 1997) for all countries except for Iceland, where the WaSiM-ETH model (Schulla and Jasper, 2001) was used. The HBV model is a conceptual, semi-distributed precipitation-runoff model. The model includes routines for snow accumulation and melt, soil moisture accounting, groundwater response and river routing. It exists in different versions in each of the Nordic countries. Due to the geological conditions prevailing in Iceland the hydrological model structure must be able to describe groundwater flow in aquifers with large vertical extent. WaSiM-ETH was chosen because it allows the user to choose modules with different levels of complexity for simulation of subsurface processes. The hydrological models were calibrated to catchments representing different runoff regimes and land surface characteristics in each country. Landscape elements which could be expected to have similar hydrological behaviour were parameterised in the same way, and calibrated parameter sets were transferred to ungauged catchments based on a classification of land surface properties. Temperature and precipitation data from the meteorological stations of the different countries were interpolated to the computational elements of the hydrological models.

RESULTS AND DISCUSSION

Maps of projected runoff changes presented in Figures 1 and 2 show that annual runoff will generally increase for the Nordic region, except for southern parts of Sweden. Latvia and some regions in southern Norway will also experience reduced annual runoff for some scenarios. Furtermore, results presented by Beldring et al. (2006) show that there will be an increase in runoff everywhere in the winter, increase in mountainous basins and inland basins in the spring, and a decline in coastal and southern basins in the spring. Decrease will occur almost everywhere in the summer with the possibility for more severe droughts. The exceptions are parts of Finland and some coastal regions in Norway. Autumn runoff will generally increase in northern and high elevation parts of the Nordic region, while a decrease is expected in southern parts. Runoff changes in the Nordic countries are strongly linked to changes in snow regime. Snow cover will be more unstable and all scenarios indicate increase in winter and autumn runoff in areas where the snow cover has a major impact on runoff in the control climate. These results are caused by the combined effects of higher temperature and more precipitation in the winter in the scenario climate. Reduced snow cover leads to smaller snow melt floods, while increased precipitation where a larger proportion falls as rain will increase rain floods, and possibly also combined snow melt and rain floods. The projected changes in runoff differ between the two general circulation models HadAM3H and ECHAM4/OPYC3 due to different modes of natural climate variability represented by the two models. These two general circulation models result in different dominating atmospheric circulation patterns, with increasing dominance from the west in ECHAM4/OPYC3 scenarios and a more easterly pattern in the HadAM3H scenarios. This results in different distributions of precipitation, runoff and other hydrological variables (Tveito and Roald, 2005). Furthermore, the A2 and B2 scenarios result in different projections of future radiative forcing and temperature changes, with A2 yielding the largest increase in greenhouse gas concentrations and temperature. These differences influence the hydrological cycle, leading to different changes in hydrological state variables and fluxes. Figures 3 and 4 show that summer streamflow from catchments Nigardsbrevatn (75 % glaciated) in western Norway and Engabrevatn (76 % glaciated) in northern Norway will increase in a warmer climate under the assumption that glaciers do not retreat, whereas summer streamflow will be reduced if the glaciers melt completely. Snow storage is important in the scenario climate in these catchments, regardless of the extent of glaciers.

CONCLUSIONS

Projections of climate change impacts on water resources in the Nordic countries have been quantified using combinations of two greenhouse gas emission scenarios, two general circulation models, two regional climate models and two hydrological models. Overall the maps show an increase in runoff, but in some areas dryer conditions are indicated. The latter may be due to decreased precipitation or an increase in evaporation that overrides the increase in precipitation. Water shortage may become a problem in some locations for the summer season. The use of several global climate scenarios gives an indication of the involved uncertainties. The hydrological climate change scenarios vary due to different dominance of atmospheric circulation patterns in the general circulation models and different external forcing caused by greenhouse gas emissions. The glacier sensitivity study shows that if the investigated catchments remain glacier dominated, summer streamflow will increase due to enhanced melt rate of glacier ice. Complete melting of the glaciers leads to a reduction in summer streamflow.

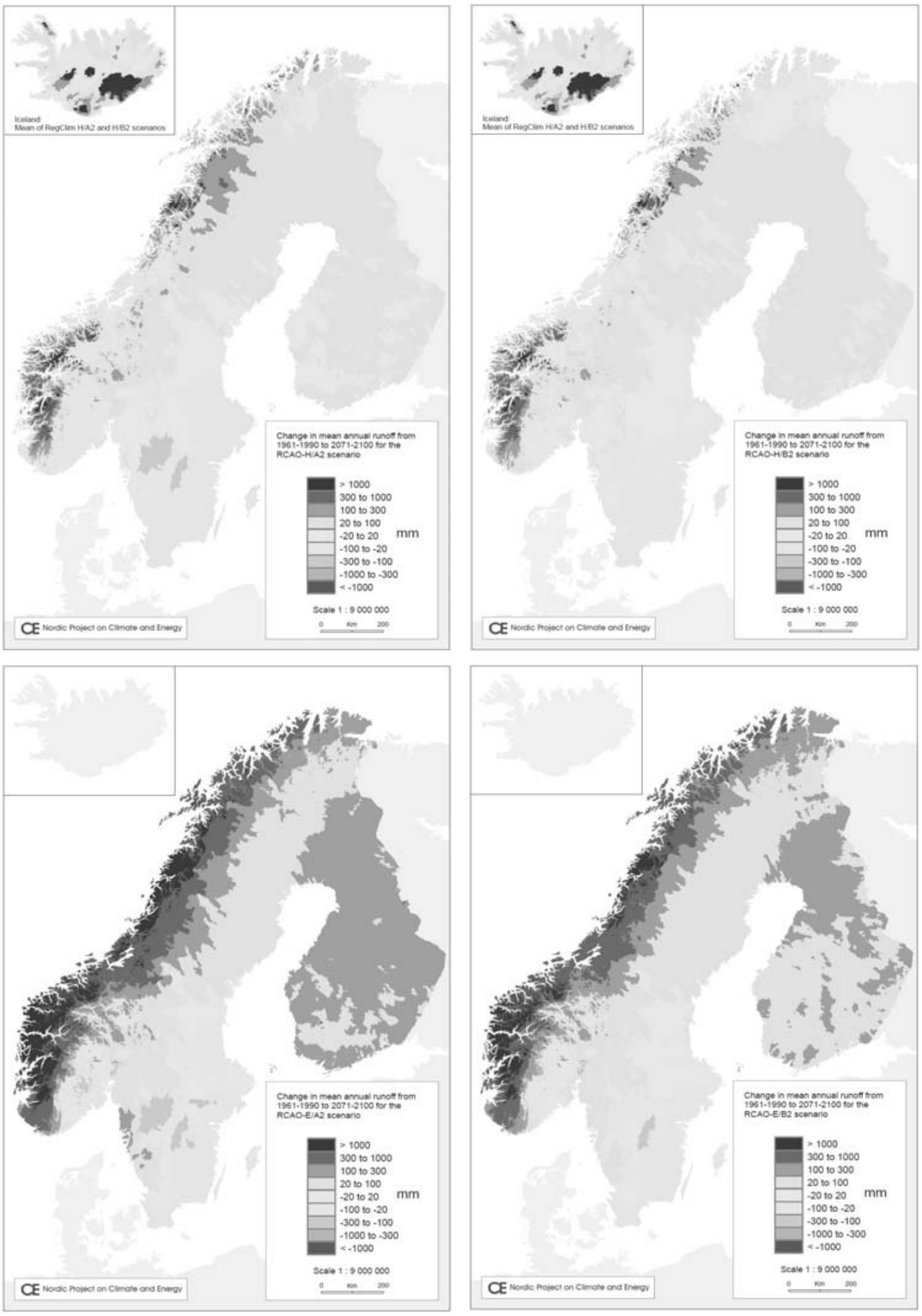

Figure 1. Change in mean annual runoff (mm) for Finland, Iceland, Norway and Sweden from 1961-1990 to 2071-2100. Top left: HadAM3H/A2 scenario. Top right: HadAM3H/B2 scenario. Bottom left: ECHAM4/OPYC3/A2 scenario. Bottom right: ECHAM4/OPYC3/B2 scenario.

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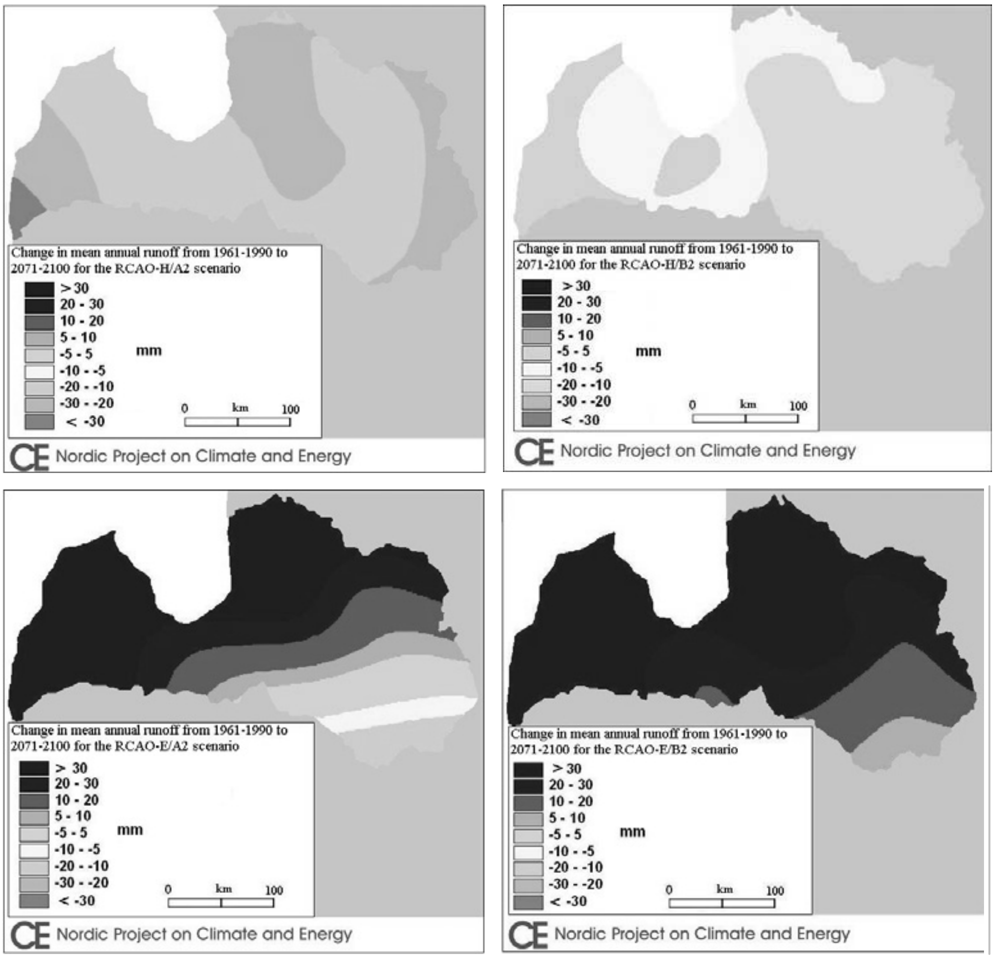

Figure 2. Change in mean annual runoff (mm) for Latvia from 1961-1990 to 2071-2100. Top left: HadAM3H/A2 scenario. Top right: HadAM3H/B2 scenario. Bottom left: ECHAM4/OPYC3/A2 scenario. Bottom right: ECHAM4/OPYC3/B2 scenario.

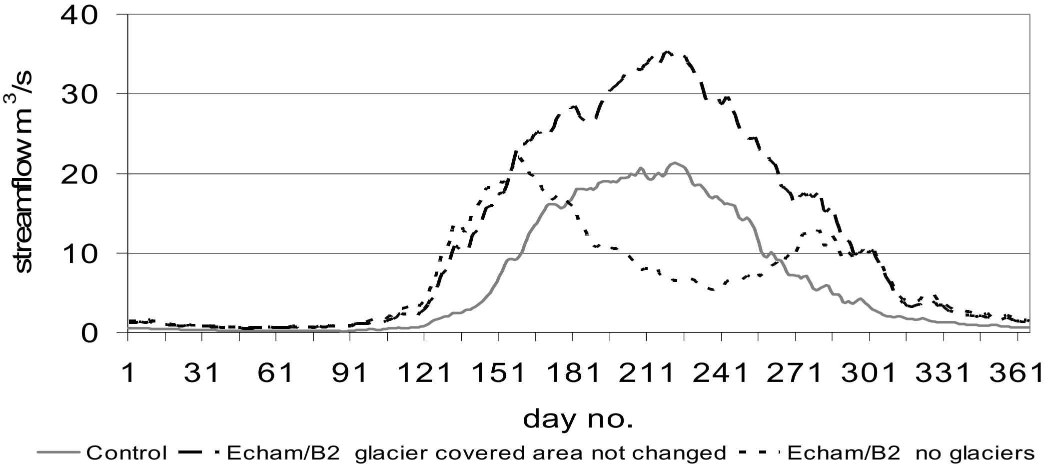

Figure 3. Daily mean streamflow for Nigardsbrevatn for control period 1961-1990 with present glacier area. Projected daily mean streamflow for 2071-2100 for ECHAM4/OPYC3/B2 scenario with no change in glacier covered area, and with the assumption that glacier covered area is zero.

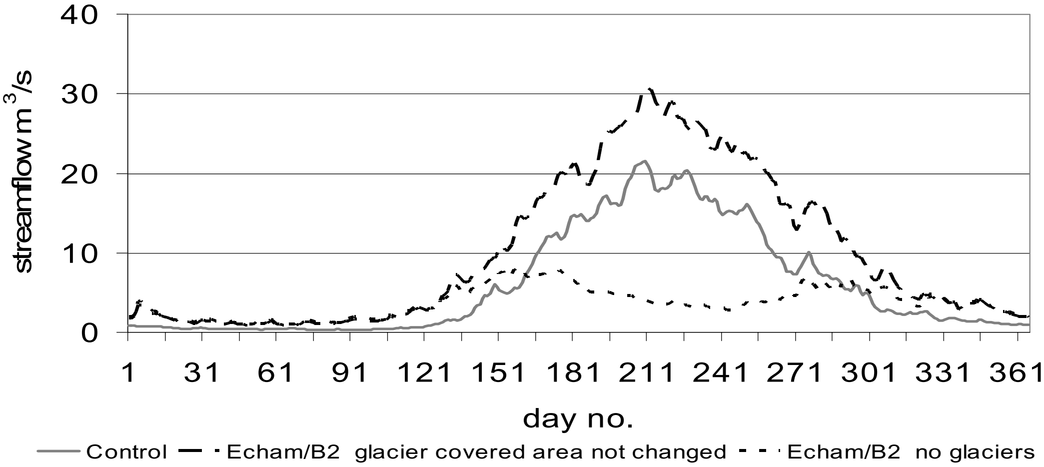

Figure 4. Daily mean streamflow for Engabrevatn for control period 1961-1990 with present glacier area. Projected daily mean streamflow for 2071-2100 for ECHAM4/OPYC3/B2 scenario with no change in glacier covered area, and with the assumption that glacier covered area is zero.

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Climate changes – some observations in Croatia

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Keywords: precipitation, surface water, temperature, changes, water resources management

ABSTRACT

This paper presents some measurements of climatic elements (temperature, precipitation) and surface water in Croatia, which indicate, like in the rest of the world, significant changes in last twenty years. Recognized changes in climate elements and regime of the surface water indicate consequences on water resources management and necessity for investigation of the causes, which affected the changes, and appropriate planning and realization of meteorological and hydrological measurements (quality of measurements (distribution, period, instruments) and quality of interpretation).

FOREWORD

Analysing climatic elements on the Drava river basin, the Lika area and Primorje show that the climatic patterns formed on the present meteorological observations are going through some changes. The results of conducted researches show what these changes are and in when they occur.

This paper shows the results of researches main climatic elements, precipitation and air temperature, which have the dominant role in climate formation and water patterns of certain areas. Also shown are the discharges which are influenced by the change in temperature and precipitation patterns.

CHARACTERISTICS OF ANALYZED AREAS

The Drava river area (Figure 1) in Croatia with its 7440 km^2 includes the area of Pannonian Basin and several mountainous areas with a number of larger and smaller streams flowing into the Drava river. In this area, the average mountain altitudes range from 100 to 800 m above sea level.

Lika mostly comprises of mountainous areas (Figure 2). The highest mountain peaks range between 1500 and 1700 m above sea level. Within these mountain ranges, many karst plateaus are located at relatively high altitudes, ranging from 450 to 700 m above sea level. Streams rich with water run through and sink into these plateaus. Major rivers are Lika and Gacka, considered among the longest underground streams in the world.

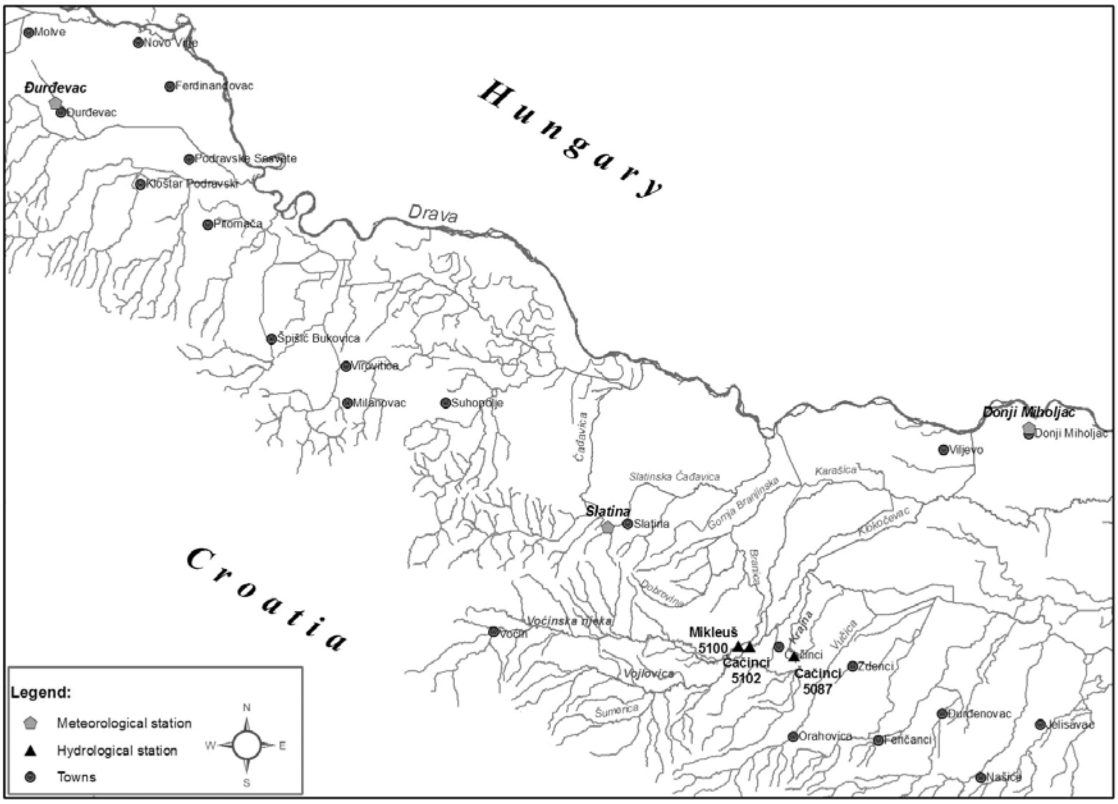


Figure 1 Drava River Basin

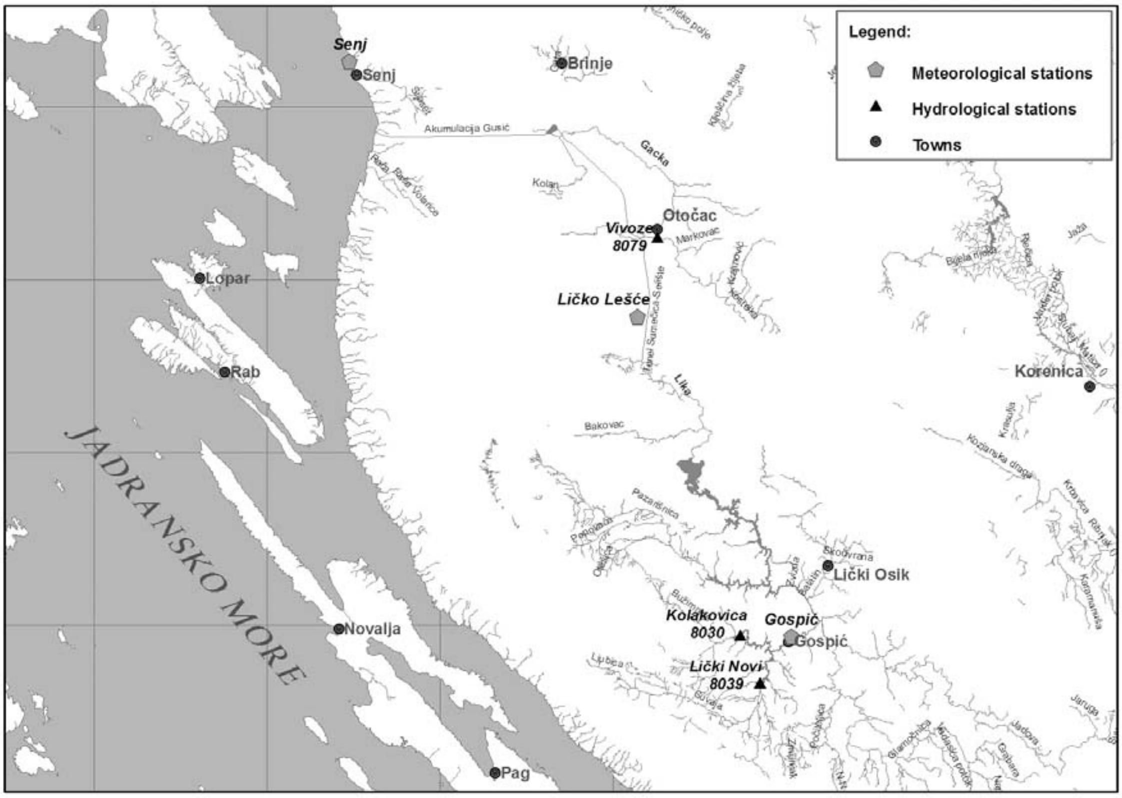


Figure 2 Lika and Primorje area

The observed area has Mediterranean, continental and mountain climate with transitional areas between these climate types.

The average yearly precipitation of the Drava river area ranges from 700 mm to 1200 mm. In Primorje, it ranges from 1300 mm to 1400 mm. In the Lika area, including its mountain regions, the average yearly precipitation ranges from 1200 mm to 3500 mm.

The average yearly temperature of the Drava river area ranges from 10°C to 11°C. In the Primorje area, this is 14, 7°C (Senj) and inland it is 8, 7°C (Gospić).

THE CHANGE IN THE PRECIPITATION PATTERNS

The Drava River (Figure 1) For climate stations Durdevac, Slatina and Donji Miholjac yearly course for two characteristic periods from 1961 to 1990 and from 1991 to 2003 was observed as shown on Figure 3. In the period from 1961-1990 precipitation maximum was mainly observed in June, which was considered as one of the main characteristics of the continental precipitation pattern. After 1990 the heaviest precipitations appear in September. This change in September especially comes into significance because September, alongside February and October, was before the change among the driest months in this area. The difference in average precipitation for the month of September in the two observed periods ranges for particular rain gauge stations from 71% even to 93%. This is the increase of average precipitation in September for the 1991-2003 period.

The change in the precipitation patterns affects the change of the water patterns, which can be partially seen on the Figure 4, which shows the yearly discharge course for three rivers.

The Lika and Primorje area (Figure 2) In this area stronger or weaker Mediterranean climatic influence prevails and its characteristic is that the most of the yearly precipitation is in the cold part of the year (around 60%). Figure 5 shows a yearly course of precipitation for two characteristic periods from 1961-1990 and 1991-2005. There are no major differences in average yearly precipitations for these two periods. The difference is in the redistribution of precipitation within a year. The influence of the precipitation change on the river discharges can be seen on Figure 6.

TEMPERATURE CHANGES

Natural fluctuations in temperature in the last two decades have been disturbed by the excessive pollution of atmosphere, so now they include exceptionally unfavourable and uncertain trend of temperature increase.

The Drava River The air temperature in the Drava river basin was observed from the climate station Durdevac and Donji Miholjac for the period of 1961-2003.

The change in temperature over time is noticeable on the diagram of the mean yearly temperature for Durdevac on the Figure 6 and for Donji Miholjac on the Figure 7. These changes are occurred since 1987. The average yearly air temperature on the climate station Durdevac has increased by 1,16 °C in the 1988-2003 period with regard to the 1966-1987 period, and on the climate station Donji Miholjac it increased by 0,87 °C.

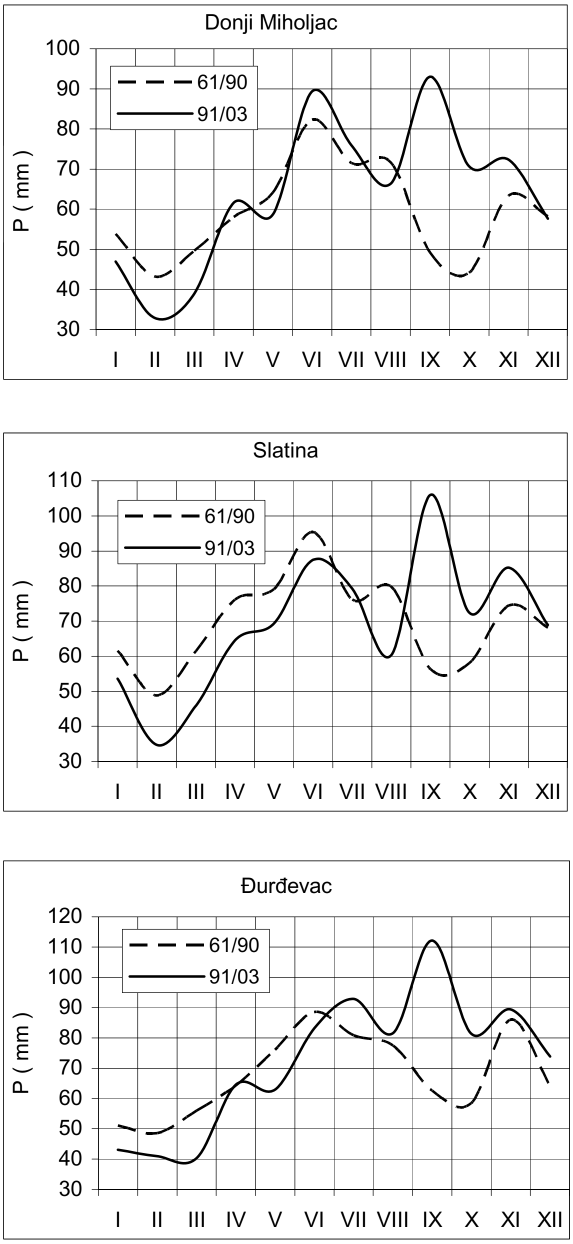


Figure 3 Rainfall – monthly variations

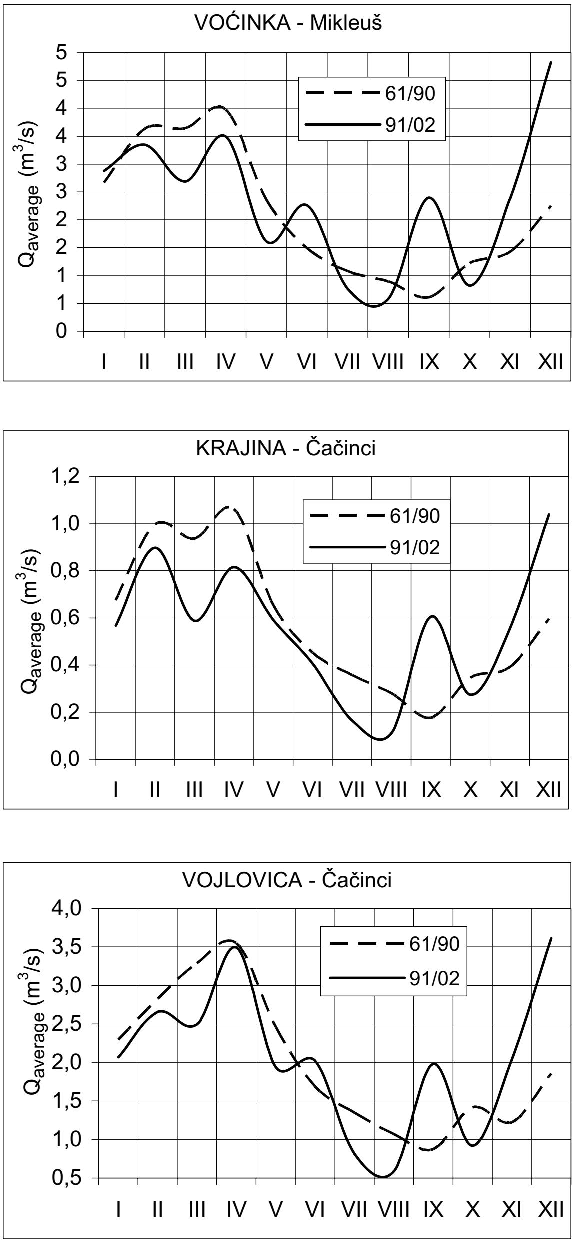
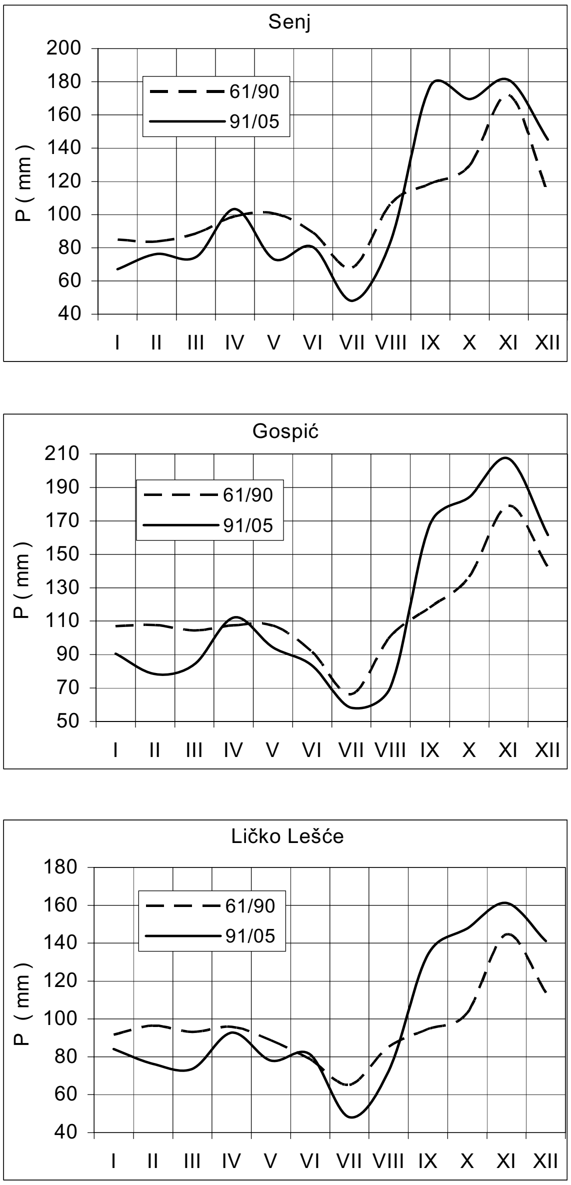


Figure 4 Hydrograph – Drava river area

The Lika and Primorje area In the Lika and Primorje area air temperatures from meteorological stations Senj, Gospic and Licko Lesce have been observed for the 1961-2005 period.

The mean yearly temperature reached in 45 year the highest value on all stations in the year 2000. The maximum monthly mean temperatures, for these stations were in the last 45 years the highest in May, June and August of 2003. The majority of absolute maximum monthly temperatures were registered in the last two decades. However, a few absolute minimums were registered in that period. With an aim of pointing out changes in temperature over the last years, mean yearly temperatures for Senj are shown in Figure 8 and for Gospic in Figure 9. The figures of mean yearly temperatures and conducted tests have affirmed that the increase of mean yearly temperatures has appeared at the end of the eighties. The increase of average yearly air temperature for Senj between the 1961-1987 and 1988-2005 periods amounts to 0,8 °C, and 0,9 °C for Gospic.



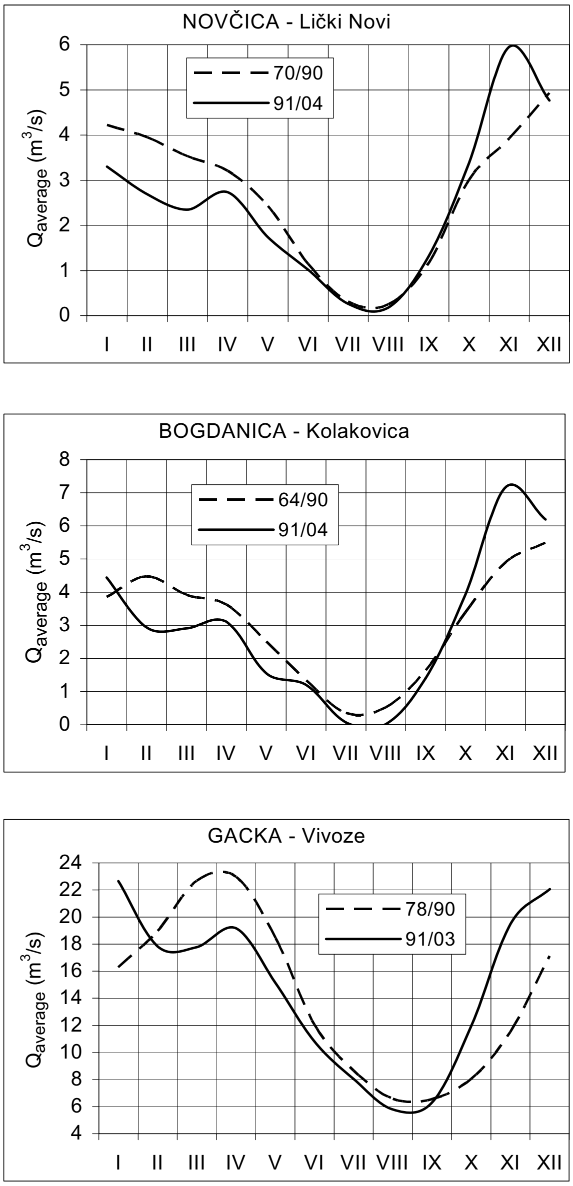


Figure 5 Rainfall – monthly variations

Figure 6 Hydrograph – Lika area

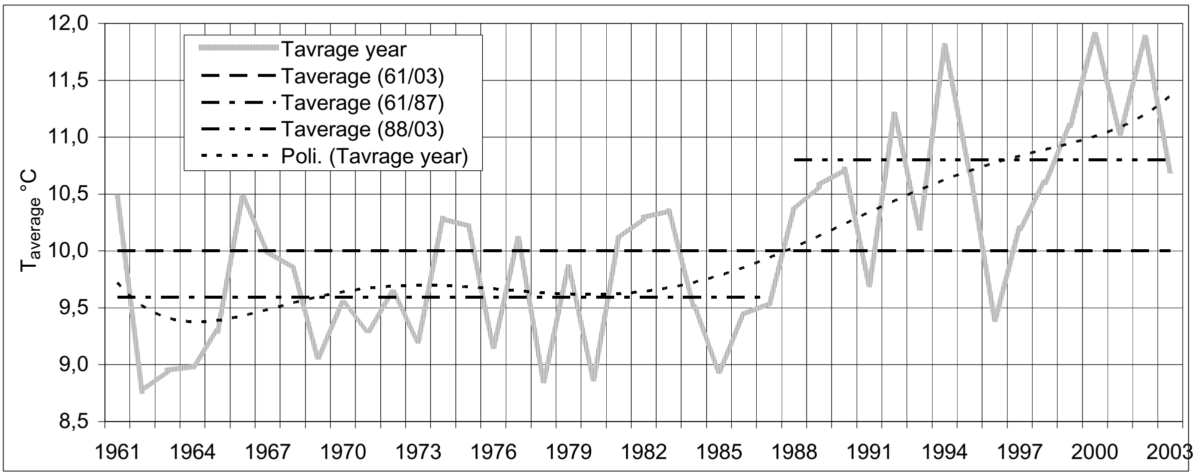


Figure 7 Mean annual air temperature – Djurdjevac

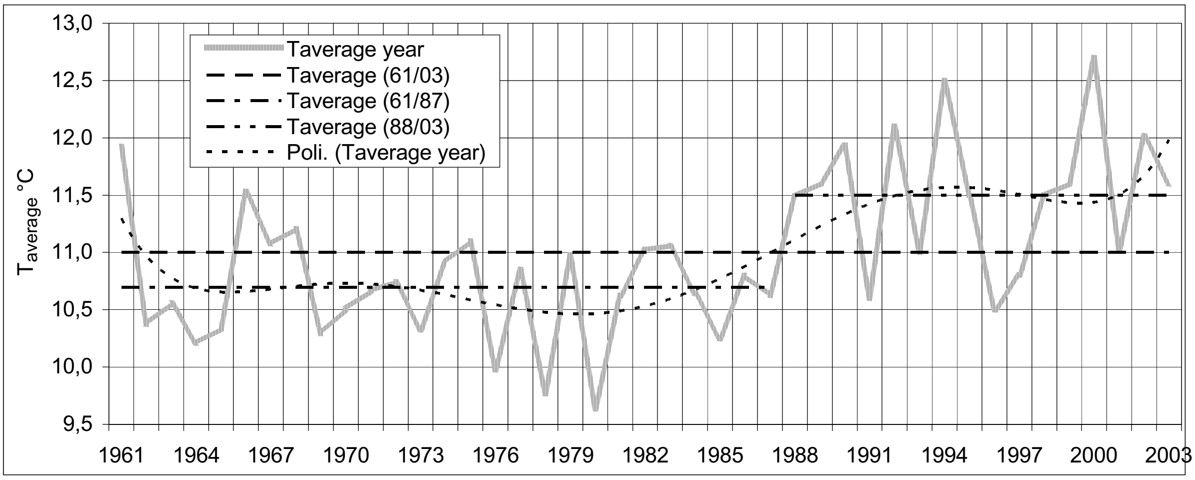


Figure 8 Mean annual air temperature – Donji Miholjac

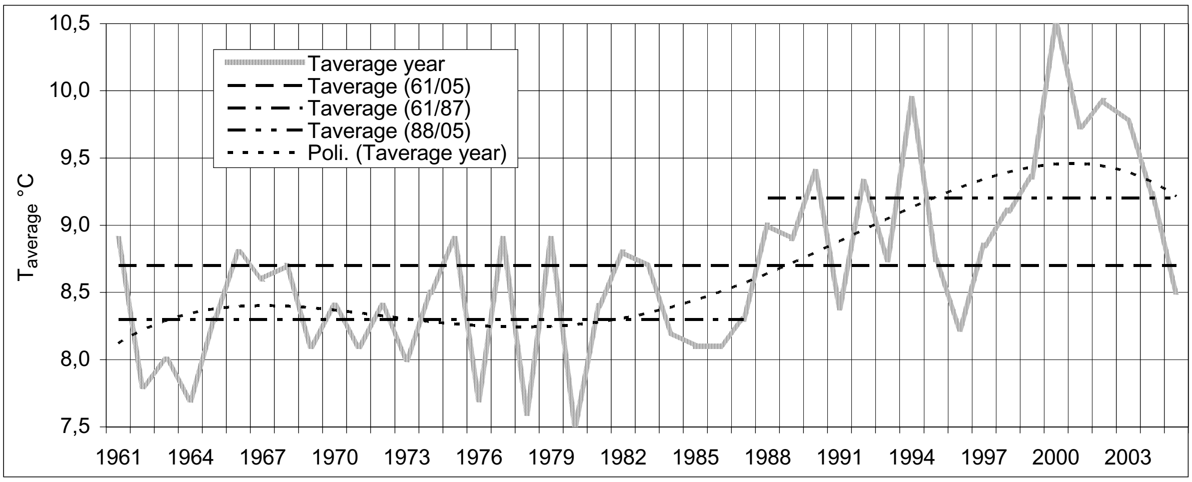


Figure 9 Mean annual air temperature – Gospić

CONCLUDING DISCUSSION

The conducted examinations indicate a presence of change within yearly precipitation and watercourse in Croatia, while there is no significant change in the total yearly water quantity. The observation of the mean yearly temperatures indicates an increase in the last 20 years. Noticed changes influence the agriculture and water resources management. The Lika area is rich in precipitation, but their yearly schedule is not favourable because of the redistribution of precipitation and it becomes more unfavourable. The average yearly temperature is systematically increasing, but also the absolute low extremes are getting to be even lower. The examination of precipitation and air temperature, along with the river discharge, indicate that systematic, long term and quality meteorological and hydrological observations needed as advised by World Meteorological Organization.

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Implementation of adaptive strategies for drinking water production

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Keywords: water resources management, storage, water supply, flexible strategies

ABSTRACT

This paper describes the results of a feasibility study on adaptive strategies for drinking water production in The Netherlands and Flanders. The currently applied strategies to deal with risk and uncertainty in water resources management will generally be insufficient for dealing with the anticipated increased variability induced by climate change. Climate change will result in different types of water stress: droughts, floodings, rainstorms and decline in water quality. New adaptive strategies for management of natural resources of drinking water production are needed and must be developed. Examples are production of drinking water from alternative resources such as sea water, precipitation, brackish ground water and domestic wastewater, using innovative treatment techniques such as membrane technology, temporary storage of excess run off water, and flexible production strategies, using various resources and treatment techniques.

The development of flexible adaptive strategies will benefit from joint research on the interactive impacts of climate change and other pressures. The high uncertainties associated with climate change, however, make efficient planning, prediction and investment extremely complicated. In addition, transition to flexible adaptive strategies will probably take decades, because investment depreciation periods of assets are long.

INTRODUCTION

Concern for the impact of climate change on ecosystems is increasing. Climate change affects water system dynamics through temperature changes, changes in precipitation patterns (more extreme floods), an increase in summer evaporation and a decrease in snow-fed river run off (extended droughts). These changes will have major impacts on the management of coastal water systems and river catchments (EEA, 2001). The capacity of water systems to cope with changing dynamics depends strongly on soil characteristics, presence of inundation areas and run-off management.

Generally, climate change impact assessments focus on risks of flooding of heavily populated coastal areas and hydrodynamic effects on navigation, agriculture and energy production (EEA, 2007). Moreover, the frequency of occurrence of low and very low river discharges increases, as calculated for the river Rhine (Shabalova et al., 2003). Extended droughts and associated water quality effects are not sufficiently recognized so far, although they may have huge economic effects on agricultural and drinking water production.

Production of reliable drinking water is of major importance for society as drinking water is the number one requirement for life. Therefore, reduced availability of freshwater and decreasing water quality are of growing concern to almost all countries of Europe. Water utility companies and governments are mainly focused on solving the problems of today, i.e. renovating existing water production facilities. However, the vulnerability of drinking water production demands a careful evaluation of future threats of our natural water resources.
Kabat et al. (2005) state that climate should not only be seen as a threath, but could also create opportunities for large-scale innovations. In this paper, the results of a feasibility study on innovative adaptive strategies for drinking water production in The Netherlands and Flanders are described.

WATER STRESS FOR DRINKING WATER PRODUCTION

Drinking water supply companies are challenged by increased variation in water availability, water quality, production, distribution, and water demand. This paper focuses mainly on the availability and quality of water resources for the production of drinking water. The tendency towards more extremes will result in a lowering of groundwater tables, a reduction of the capacity of water reservoirs, as well as water quality effects.

Groundwater and surface water dynamics are expected to change significantly. In parts of The Netherlands the groundwater table may be lowered tens of centimetres during dry periods (Cirkel et al., 2006). This may have serious consequences for the use of groundwater as a source for drinking water production given the effects on terrestrial ecosystems. The anticipated effects are even more pronounced when the increase in agricultural and drinking water demand during periods of water scarcity is taken into account.

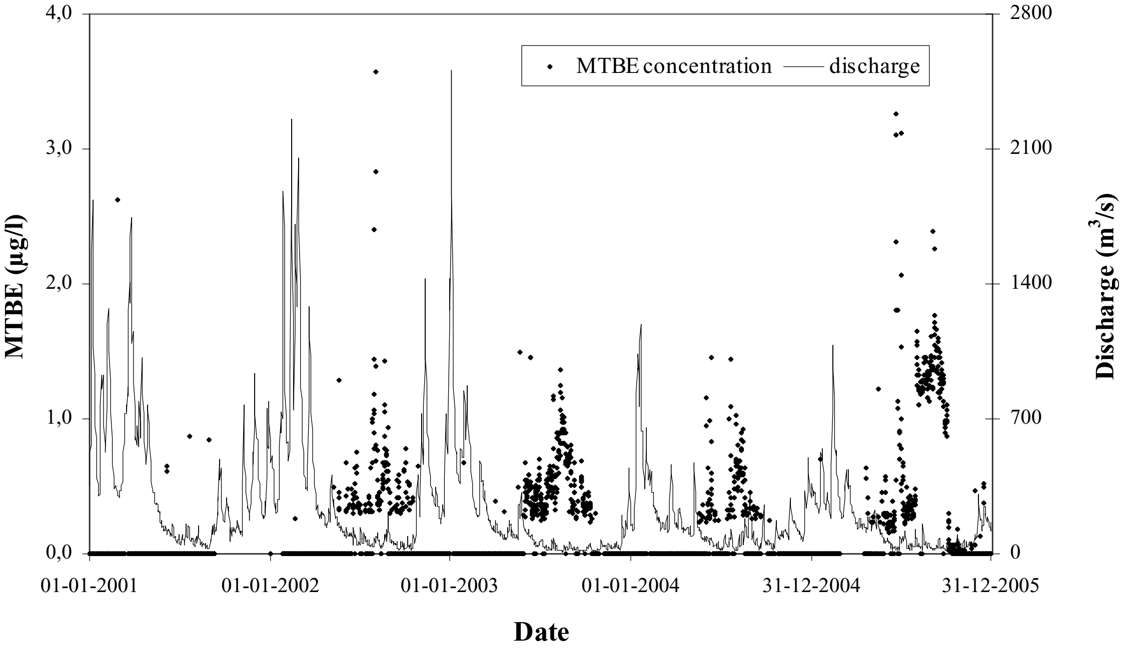

Figure 1. MTBE concentrations and river discharge at the measuring station Eijsden in the river Meuse during the period 2001-2005 (data from www.aqualarm.nl and www.waterbase.nl)

The trend towards more frequent and extended droughts is expected to cause problems for drinking water supply companies with respect to contamination of surface water systems. This may ultimately result in additional and elongated intake stops. Low river discharges are generally accompanied by less dilution of the pollution load, resulting in higher concentrations of contaminants. This is clearly illustrated in figure 1. Methyl tert-butyl ether (MTBE), the most widely used oxygenate in gasoline, shows a seasonal pattern at the measuring station Eijsden, located at the Dutch-Belgian border, with high concentrations at low discharge of the rain dominated river Meuse. Given the absence of official quality standards for drinking water and intake of surface water, drinking water supply companies commonly use an indicator value of 1 µg/l MTBE. When predicting the effects of more pronounced droughts on river quality, substitute products should also be taken into account. An example of this is the expected shift from MTBE to ETBE (ethyl tert-butyl ether) (Deeb et al., 2003).

Similarly, reduced dilution of pollution loads is expected for compounds that are emitted to the surface water at a constant rate, e.g. via effluents of industrial or domestic waste water treatment plants (WWTP). Several emerging compounds, like pharmaceutical residues and endocrine disruptive compounds, may consequently be observed more frequently in surface water. As these compounds are considered unfavourable in drinking water, environmental standards should be set to actively control emissions to the surface water. Other relevant parameters, like oxygen and algae levels (including the toxic blue algae), are also significantly influenced by extended droughts. Floods will temporarily be accompanied by increased suspended matter levels and associated contaminants in rivers (Doomen et al., 2007), giving rise to intake problems. During 2006 the water company Evides already had to close down their intake for 47 days due to the presence of high levels of suspended matter in the river Meuse during floods.

Groundwater in the coastal region of the Netherlands is very vulnerable to salinisation. Given the increasing salinisation of the groundwater by maritime (related to recent north Sea intrusion and upconing of ancient North Sea water) and continental (related to agriculture, evaporation, bank infiltration, artifical recharge and local pollution) causes (Stuyfzand, 1996), surface water is nowadays the main source for drinking water production in the western (low) part of the Netherlands, including the cities Amsterdam, Rotterdam and The Hague, as well as Brussels and Antwerp in Belgium. Different treatment techniques are applied to produce drinking water. These include abstraction from the rivers Meuse and Rhine (including the Lek canal and Lake IJssel), plus temporary storage in large drinking water reservoirs, the use of dune infiltration and extraction, and extraction after bank filtration. Relatively advanced treatment technologies are generally applied to produce high quality drinking water from (contaminated) surface water.

Recently, changes in salinisation of the estuary of the rivers Rhine and Meuse in the Netherlands within a time span of 50 years have been predicted (Doomen & Van den Berg, 2005). This study shows that effects of climate change cannot be predicted reliably without a systematic knowledge of the effects of other major developments, such as the reconstruction of natural estuarine conditions, measures to ensure freshwater supply to regional water systems (given agricultural functions), and dredging to increase the navigation depth. Future salinity gradients in the estuary are mainly determined by autonomous developments related to climate change. An increased salinisation of the Rhine-Meuse estuary is caused by a combination of increased water levels at sea, more frequent and heavier winds from sea, and lower river discharge. Lower river discharges are accompanied by significantly higher chloride levels during dry periods (assuming the present salt load). This will negatively influence the public (and agricultural) water supply in the area. Increased salinisation will also threaten the salinity of bank filtrate. Locally, the yearly average chloride concentration may increase substantially by salinisation, resulting in a decreased functionality of the abstraction.

NEED FOR ADAPTIVE STRATEGIES

Climate change and other threatening environmental and spatial developments stress the necessity to develop innovative concepts for drinking water production. It is now generally acknowledged within the drinking water sector in The Netherlands and Flanders that adaptive strategies need to be developed and implemented to secure the supply of high quality drinking water.

Demand strategies aim at changing the public awareness towards the use of drinking water. Measures at the demand side ask for a sectoral approach, preferably at river basin scale or regional scale. Such measures include e.g. a reduction in water consumption, introduction of progressive water pricing and setting of specific regulations regarding the use of drinking water during periods of water scarcity. Supply strategies aim at the development and implementation of adaptive measures to manage dynamic water systems. The focus should be on costs, customer perception and environmental sustainability. Worldwide, studies have focussed on the exploitation of sea water, precipitation, brackish ground water and domestic wastewater, using innovative treatment, such as membrane technology, as alternatives to commonly applied water resources, like fresh groundwater and surface water. Some concepts are already widely applied in specific regions. Desalination, for example, is a commonly applied technique in densely populated (semi) arid areas, like the Mediterranean countries. Drawbacks of this technique are the high investment costs and energy consumption.

The Dutch water cycle company Waternet has recently investigated the potential use of alternative resources for the production of drinking water from river Rhine (Lek canal) water (Bernhardi & Van den Berg, 2006). These include abstraction of water from large freshwater reservoirs (Lake IJssel and Lake Marken), abstraction of surface water from artificial canals (polder storage), surrounding the city of Amsterdam, use of brackish seepage water, and the use of domestic waste water from a large domestic WWTP. Table 1 shows that each potential source has typical quality aspects, which may require redesign of the present treatment procedure for producing drinking water. Additionally, it is shown that the expected future continuity of these alternative resources, based on the combined effects of climate change and realisation of water management goals at local and river basin scale, varies widely. The availability of some of the proposed sources is too small to become the single alternative for the present water resource.

Table 1. Assesment of the relative suitability of potential sources for the future drinking water supply of Waternet (Bernhardi & Van den Berg, 2006). Infrastructural and treatment requirements have not been taken into account.

Source	Salinity	Micro pollutants	Seasonal variability	Availability	Continuity	Quality aspect
River Rhine*	0	0	high	+	-	temperature
Lake IJssel	0	+	high	+	-	algae
Lake Marken	0	+	high	+	0	SPM
AC Rijnland	--	-	high	+	-	chloride
AC Amstel	--	-	high	-	-	chloride
River Vecht	-	--	high	-	+	effluents
Seepage water	--	+	low	0	0	chloride
WWTP	0	--	low	+	+	micro's

*present source (Lek canal); SPM = suspended matter; AC = artificial canals; WWTP waste water treatment plant; -- very poor; - poor; 0 neutral; + favourable.

In another project, eight possible sources for drinking water production (shallow, deep and hard groundwater, river bank filtrate, brackish groundwater, surface water, WWTP effluent and rain water) have been evaluated for treatment (investment and operational) costs (Meuleman et al., 2006). They conclude that rain water and brackish ground water could be cost competitive alternatives for current drinking water sources.

A few years ago the 'fresh keeper' concept has been developed (Kooiman et al., 2004). This multiple source concept has advantages over the separate extraction of either freshwater or brackish groundwater. Additional deep wells protect existing freshwater wells from upconing brackish groundwater. The brackish groundwater extracted can be utilized for drinking water production using reversed osmosis, thus improving the capacity of existing well fields. Pilot studies are now initiated by drinking water supply companies to test this concept under field conditions. The legal aspects of membrane concentrate disposal needs special attention (Bernhardi et al., 2006).

Flexible water resources management and treatment is a promising concept for continuous and sustainable production and supply of high quality drinking water (Meuleman et al., 2006). Application of the Flex Water concept is based on large treatment systems, designed for constant production, combined with flexible sources te deal with peak demands. This concept optimizes the use of seasonally available natural resources in combination with temporary storage to match peak demand and extreme events to secure continuous drinking water supply. A major advantage of the Flex Water concept is the possibility to link water sources with limited capacity. This promotes shifts between different sources.

The Flex Water concept is expected to be cost efficient in remote areas and newly developed urban areas. The use of locally available water resources is an important element of this concept. De Graaf & Van de Ven (2005) describe the use of local rainfall for drinking water production in urban areas (closed city concept). At this moment, strategic studies are initiated to experiment with such self supporting systems. During dry periods recycled WWTP effluent and regional surface water may be used as supplementary sources to create a more flexible system. This can reduce vulnerability of urban areas to changing water dynamics.

An example of the Flex Water concept is the use of excess rain water or pretreated surface water as additional sources for drinking water in combination with temporary storage in aquifers with Aquifer Storage and Recovery (ASR) which can be used during dry periods. At several locations (e.g. in the US, Israel, UK, Canada, and Australia) this concept is already applied. In The Netherlands one succesful pilot has been completed. Relevant for implementation is knowledge of changes in water quality of the injected water (Prommer & Stuyfzand, 2005). The ASR concept is comparable to the application of aquifer thermal energy storage (ATES).

Besides the development and implementation of innovative concepts to improve water resources management, techniques used to extract groundwater can also be improved to challenge effects of climate change. An interesting example is the application of horizontal directional drilled wells (HDDW) in public water supply. Nowadays, groundwater in The Netherlands and Flanders is mainly extracted using conventional vertical wells. The use of HDDW will increase the flexibility of a well field, because it causes less drawdowm of the groundwater over a larger area with respect to conventional wells (Fournier, 2005). So far, HDDW has been mainly applied in soil remediation sites.

DISCUSSION AND SYNTHESIS

Knowledge of climate change effects on drinking water supply is increasing. It is now generally accepted by drinking water supply companies in The Netherlands and Flanders that climate change may affect water resources management in the near future. Measures are needed to mitigate the impacts of dynamic natural conditions on water supply, taking into account both quantity and quality aspects. In this paper some innovative adaptive concepts to deal with the anticipated changes were presented. These include the use of new water resources, as well as multiple sources and flexible sources concepts.

An integral approach needs to be developed that takes into account the specific functions of water systems, such as drinking water, agriculture, cooling and ecology. A successful water management tool to improve the sustainability of resources is water allocation during periods of water shortage. In The Netherlands the priority list water scarcity has been developed. It is anticipated that public water supply should prevail over other sectors, given the importance of clean drinking water for public health.

A continuous reduction of chemical pollution of water resources by improving industrial processes and waste water treatment, as well as introduction of cleaner agricultural practices will decrease the contamination of the surface water with pollutants that require intense treatment for drinking water production. Water managers should aim at a controlled permit system based on the treatment capacity of the receiving surface water and maximum acceptable concentrations in the receiving water, taking into account the relevant functions of the water system. Such strategies should preferentially be developed and implemented at a river basin scale, in accordance with the principles of the Water Framework Directive.

The development of innovative adaptive strategies will certainly benefit from joint research on the interactive impacts of climate change and other pressures. High uncertainties associated with climate change, however, make efficient planning, prediction and investment extremely complicated. Transition to flexible adaptive strategies will probably take decades because investment depreciation periods of assets are long. This implies that long-term strategies within an indicated timepath have to be developed. These strategies must be based on thorough knowledge of current assets to seize opportunities for change.

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Future flood risks around the big Swedish lakes

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Keywords: big lakes, climate change, flood risks.

ABSTRACT

A comprehensive analysis concerning present and future flood risks in the river systems of some of the biggest Swedish lakes has been elaborated by SMHI on behalf of the Swedish Commission on Climate and Vulnerability. The hydrological conditions and flood risks of the big Lake Vänern and its outlet River Göta älv, Lake Mälaren and Lake Hjälmaren are analysed in detail, both regarding problems related to today's climate and impacts of climate change.

The results show that there are great problems related to high water levels and high flows around Lake Vänern and Lake Mälaren and along River Göta älv already under present climate conditions. Actions are urgently needed to lower these risk levels. Concerning the future climate, as it is pictured by existing regional climate scenarios, the problems seem to be aggravated in particular around Lake Vänern and along River Göta älv. The problems related to the most extreme levels around Lake Mälaren and Lake Hjälmaren do not seem to change a lot, but high floods of somewhat lower return periods may become more frequent. It is shown that the problems related to Lake Vänern and River Göta älv might be somewhat alleviated by use of a new strategy for release of water, still within the framework of the existing decree by the water court.

INTRODUCTION

The big lakes in Sweden have always been subject to debate and conflicting interests. They are very attractive for recreational life and shore-near living, they are used for water supply and shipping and they cause flooding problems from time to time. On top of this the prospect of global warming has added a new dimension to the management of these lakes and risks along their shore-lines. After flood problems in the years 2000 and 2001 it was clear that the operation rules and the old decrees by the water court were not sufficient to safeguard the shores and downstream conditions of some of the biggest Swedish lakes, a situation that also affects the two largest cities in Sweden, Stockholm and Gothenburg. The Swedish Commission on Climate and Vulnerability was given the task to analyse the situation and suggest means to alleviate the problems, with focus on Lakes Vänern, Mälaren and Hjälmaren (Fig. 1). The second largest lake in Sweden, Lake Vättern was not included in the investigation. The commission delivered its recommendations in November 2007 (SoU, 2006) with support from a study carried out by SMHI (Bergström *et.al.,* 2006). The present paper is mainly based on the last one of these publications.

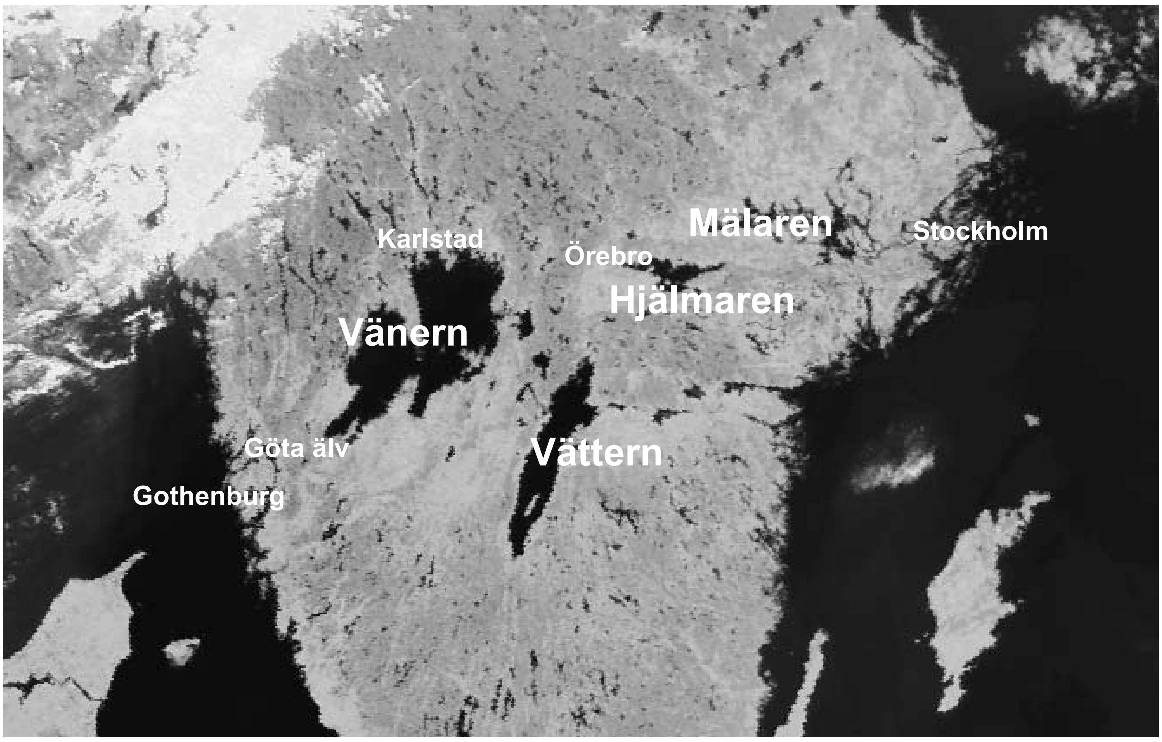

Fig.1. A satellite image showing location of the four biggest lakes in Sweden, River Göta älv and the cities of Stockholm, Göteborg, Karlstad and Örebro.

PROBLEMS ADDRESSED

Lake Vänern and River Göta älv

Lake Vänern is Sweden´s largest lake and number three in Europe. Its outlet, River Göta älv is Sweden´s biggest river. Together they form a complex system with many conflicting interests and hazards:

1. The lake level is controlled by a dam and a decree for the regulation from 1937. Experience has shown that this regulation does not guarantee acceptable water levels under extreme conditions. The city of Karlstad was, for example, at risk in 2001.
2. The pressure on exploitation of the shore-lines of Lake Vänern is increasing, and experience has shown that many of the cities may be flooded even under today's climate conditions. The same can be said about the shores of River Göta älv
3. There is substantial hydropower production in River Göta älv.
4. A permanent lowering of the lake will influence navigation, ecosystems and recreational activities around the lake and will also decrease hydropower production in the river.
5. It is dangerous to increase discharge in River Göta älv, due to the risks for land slides. The water supply for as many as 700 000 citizens in the area, including the city of Gothenburg, may be at risk.
6. High discharge in the river is also hindered by high sea levels, which cause flooding along the lower reaches of the river.
7. The complexity of the situation has triggered a debate about blasting a new outlet tunnel to the sea. This outlet should have an additional capacity of some 400 m^3/s. The environmental consequences of the tunnel would be substantial.
8. Climate scenarios show that the flooding problems, in particular in the Vänern area, are likely to increase due to global warming. Sea level rise will aggravate the situation.

To illustrate the drastic effects in Lake Vänern, caused by the decree from 1937, the water levels since 1846 are shown in Fig. 2. From the corresponding river flow in River Göta älv, shown in Fig. 3, it is clear that hydropower production has caused a dramatic increase in both variability and peak flows. Fig. 3 also shows the uniqueness of the peak in January 2001. This flow violated the regulation rules. In an attempt to reduce the high water levels the local county authority (Länsstyrelsen) ordered the dam owner to increase the discharge by some 20 % on that occasion (Bergström, *et.al.,* 2006).

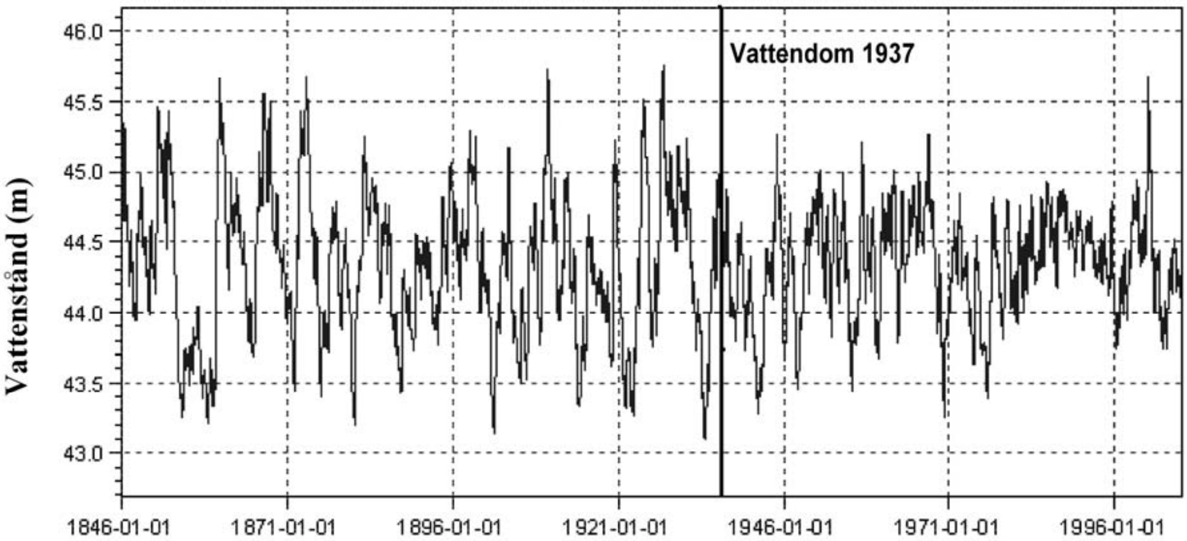

Fig. 2. Water levels in Lake Vänern 1846-2005 ("Vattendom" means decree by the water court).

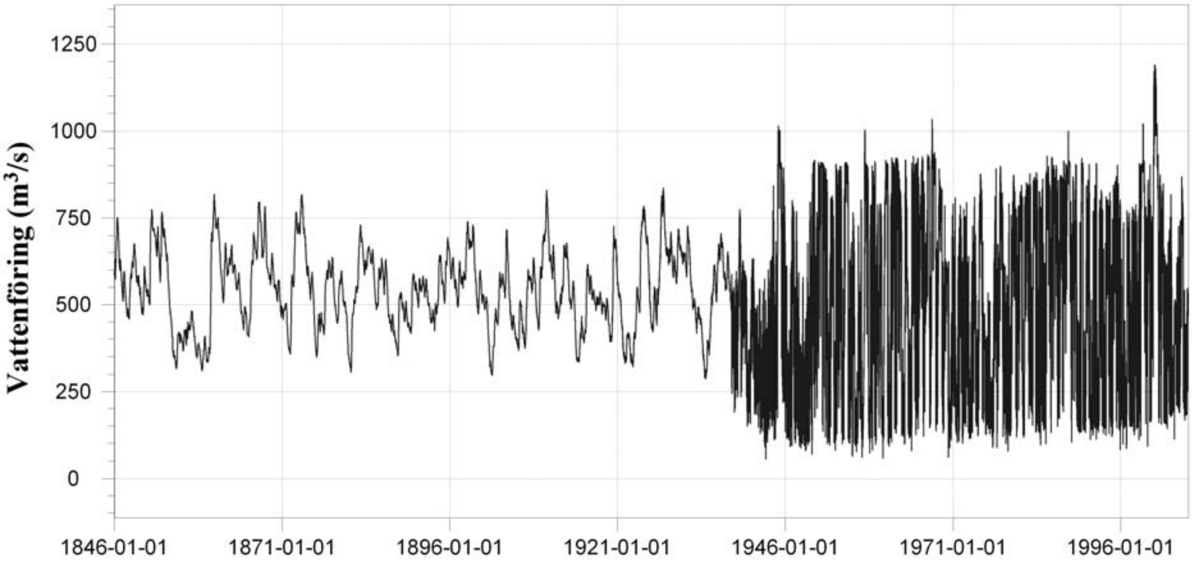

Fig. 3. River flow in River Göta älv 1846-2005. Note the drastic effect of river regulation and the unique peak of 2001.

Lake Mälaren

Lake Mälaren is number three in size in Sweden. It is strategically located upstream of Stockholm and is discharging through its down town areas into the Baltic Sea. The problems look as follows:

1. The lake level is controlled by several outlets and a decree for regulation from 1943.
2. The pressure on exploitation of the shore-lines of Lake Mälaren is very high in this metropolitan area. Experience has shown that many central facilities, including the subway of Stockholm, are in danger even under today's climate conditions.

3. A permanent lowering of the lake will influence navigation, ecosystems and recreational activities around the lake. The average level of the lake is only some 50 cm above sea level.
4. There is no river downstream, so increased discharge capacities can be achieved. The need has been estimated to a doubling of today's capacities.
5. Climate scenarios show that the moderate flooding problems are likely to increase due to global warming while the most extreme ones will not get any worse.
6. Sea level rise is not likely to increase the discharge problems, as it is more or less compensated for by the uplift of land, which is as high as 4 mm/year in the Stockholm area.

Lake Hjälmaren

Lake Hjälmaren is the fourth biggest Swedish lake. It is unique in a sense that it used to be much larger that today. Towards the end of the 19th century it was lowered more than one meter for land reclamation. This opened new possibilities for agriculture, but also for expansion of infrastructure and other developments. Örebro is the biggest city on the shoreline. The drastic effects of the lowering of the lake is clearly seen in Fig. 4.

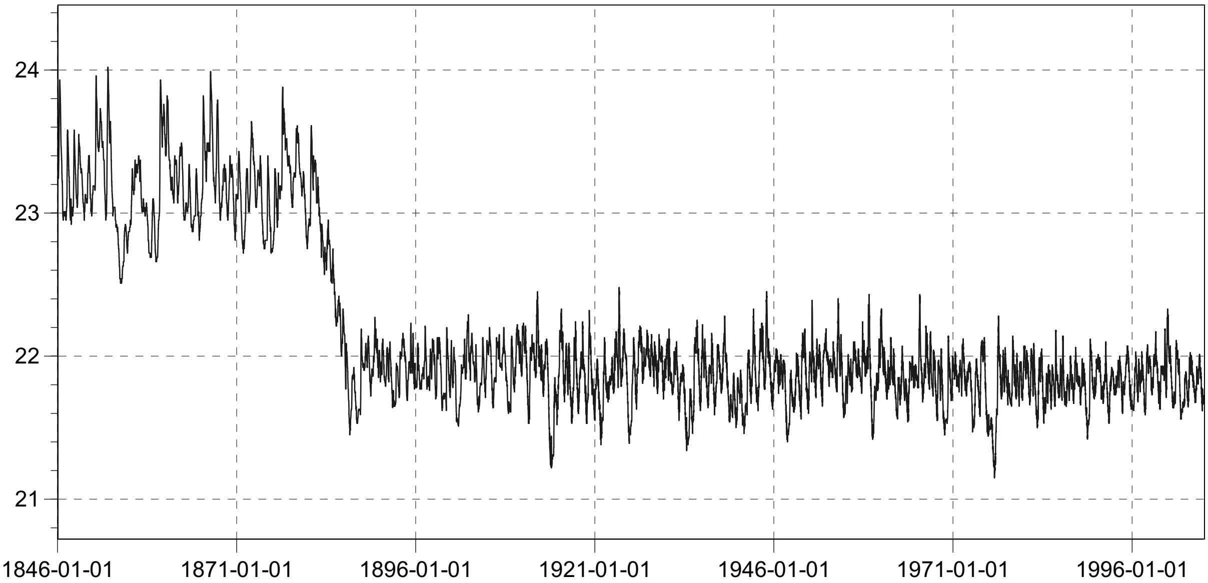

Fig. 4. Water levels in Lake Hjälmaren, showing the effects of lowering of the lake and land reclamation towards the end of the 19th century.

METHODS

The studies of the present and future conditions around Lakes Vänern, Mälaren and Hjälmaren were carried out by use of the hydrological HBV-model (Bergström, 1995), input from regional climate scenarios provided by the Rossby Centre and calculations of extreme floods in a future climate, according to the present Swedish guidelines for estimation of design floods for dams (Andréasson *et al.,* 2007). The design floods were routed through the lakes by regulation strategies, which have been tailored to mimic actual conditions as closely as possible.

Scenarios of climate change were delivered by the Rossby Centre Regional Atmosphere-Ocean Model (RCAO) (Döscher *et al*., 2002). Results from two different global General Circulation Models (GCMs) were used as boundary conditions for the regional model. The simulations were thus based on GCM results from HadAM3H from the Hadley Centre in UK and additional simulations from ECHAM4/OPYC3 from Max-Planck-Institute for Meteorology in Germany (Räisänen, *et al*., 2003). These two global models were run under future conditions with assumptions about emissions according to the A2 and B2 emission scenarios defined within the suite of SRES scenarios (Nakićenović *et al.*, 2000).

RESULTS

The simulations by the climate scenarios and the hydrological model showed that the Vänern - Göta älv system is the most vulnerable to global warming. Flood risks will increase both regarding short and long return periods. The 100-year water level will on average turn into a 20-year level around 2100 and the most extreme lake levels may increase by 50 cm. So urgent measures are required to cope with today´s problems, but margins have also to be created for future changes, due to climate change. To be able to increase discharge in the river, substantial geotechnical stabilisation measures along the river banks will be required.

A special study on a possible new regulation strategy was carried out in co-operation with Vattenfall, who is the dam owner and power producer in River Göta älv. It showed that the decree for river regulation probably leaves some freedom for modifications. This could be one means to lower the lake levels at least a few tens of centimetres under extreme conditions, without too strong effects on navigation and ecosystems. The costs in terms of loss in power production would be moderate.

The shores of Lake Mälaren, including the city of Stockholm, are also vulnerable to flooding. Discharge capacities have to be doubled, but it seems like the impact of global warming is less dramatic on this eastern side of the country. There are further no difficult downstream conditions that hinder increased flow, but the costs for the construction of a new outlet in downtown Stockholm is quite substantial.

As Lake Hjälmaren is located in a less populated area and was permanently lowered in the late 19th century, the shore lines are less developed and the risks are thus less pronounced. They can probably be managed by restrictions linked to future physical planning.

DISCUSSION AND CONCLUSIONS

The studies for the big Swedish lakes, carried out for the Swedish Commission on Climate and Vulnerability, can simply be summarised the following way: Big lakes mean big problems. And in more populated areas, with a dynamic economy and expanding infrastructure, the problems aggravate.

The results show that there are great problems related to high water levels and high flows around Lake Vänern and Lake Mälaren and along River Göta älv already under present climate conditions. Actions are urgently needed to lower these risk levels. Concerning the future climate, as it is pictured by existing regional climate scenarios, the problems seem to be aggravated, in particular around Lake Vänern and along River Göta älv. The problems related to the most extreme levels around Lake Mälaren and Lake Hjälmaren do not seem to change a lot, but high floods of somewhat lower return periods may become more frequent. It is shown that the problems related to Lake Vänern and River Göta älv might be somewhat alleviated by use of a new strategy for release of water, still within the framework of the existing decree by the water court from 1937.

The study has, however, also been encouraging, as it has made it possible to quantify some key problems. It has shown the strength in using meteorological and hydrological simulation tools in close contact with the decision makers and others who have an interest in the management of the lakes. This has, in some respect, been a pedagogical exercise, which is necessary in situations where interests are conflicting. The modelling technique has also helped identifying the limits that the natural climate conditions put to development as well as giving indications about how future global warming might affect us.

It is clear from the study that climate change adds a new dimension, which has to be considered as a limiting factor for future physical planning and infrastructure development. But it is also clear that man made changes has affected the systems before, and sometimes rather drastically, like for the river flow in River Göta älv and levels of Lake Hjälmaren.

ACKNOWLEDGEMENTS

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State of Water Resources of Mauritius in a Changing Global Climate

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Keywords: small island, rainfall trend, hydrological pattern, climate change

ABSTRACT

The Republic of Mauritius is a small island state with a fragile socio-economic structure. This is further exacerbated by the constant threat of natural disasters such as tropical cyclones, floods, periodic droughts, storm surges and tsunami. It is feared that climate change will worsen existing vulnerabilities as a result of the sea level rise, more frequent occurrences of extreme natural disasters.

The paper states that since 75% of estimated utilizable water resources have already been developed, management of water resources in Mauritius becomes more challenging. It investigates the occurrences of longer dry seasons, uneven distribution of rainfall over the year together with increasing demand.

It describes how the country suffered very acute water shortages in 1999 during the drought of the 20th century when hardly any rainfall was received for months.

It further describes a study which was carried out in order to investigate the changes in the river flow regime when problems were encountered in supplying adequate quantity of water to the population.

Data for selected rainfall stations, river flow gauging stations and reservoirs have been analysed to detect changes in the duration of dry seasons, rainfall and runoff volumes and the replenishment of reservoirs in recharge areas over high ground.

The paper offers remedial measures to mitigate the adverse impact of climate change to sustain development in the island.

INTRODUCTION

Mauritius, a small island state in the South West Indian Ocean, is under the constant threat of natural disasters such as tropical cyclones, floods, periodic droughts, storm surges and tsunami .It is feared that climate change will worsen existing vulnerabilities as a result of sea level rise and more frequent occurrences of extreme natural disasters.

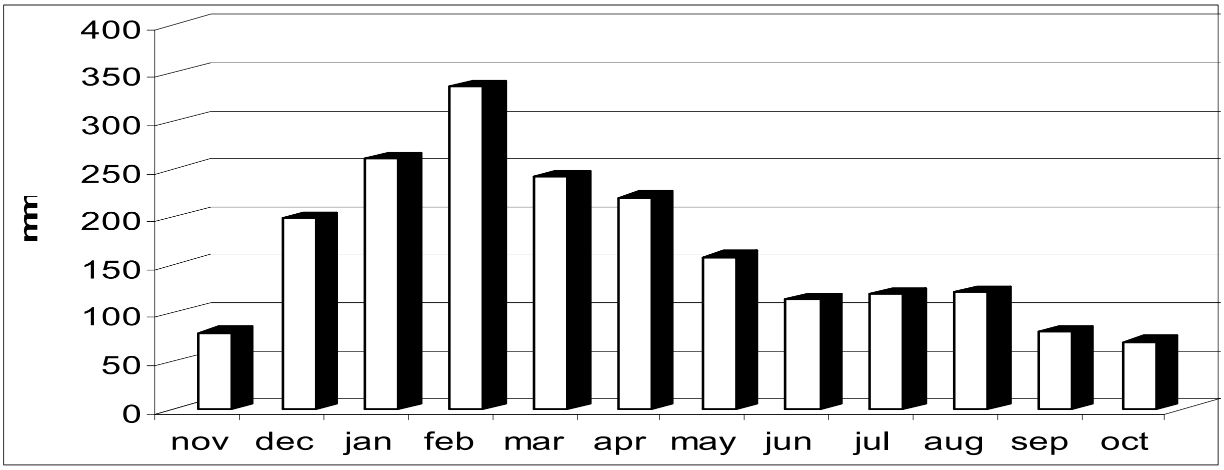
The annual volume of rainfall received over Mauritius is about 3700 Mm^3 out of which the surface runoff is about 60%, evapo-transpiration about 30% and net recharge to groundwater about 10%. Water is being abstracted from rivers, reservoirs and aquifers for potable, agricultural, industrial and hydro-power generation purposes. The biggest water user is the agricultural sector with 46%, hydropower generation is second with 32% and potable water supply is third with 21%. 56% of water is being directly abstracted from unregulated river runoff; 28% from the reservoirs and 16% from the aquifers. The estimated utilizable water resources potential is of the order of 1233 Mm^3/year. 920 Mm^3, 75% of the volume, has already been developed.

Mauritius has a tropical maritime climate with two seasons: (1) summer from November to April and (2) winter from May to October. Rainfall varies from 1400 mm on the eastern coast to 4000 mm on the central plateau and 600 mm on the western coast. The annual potential evaporation ranges between 1100 mm and 1600 mm. The relative humidity has an average value of 80%. The South East Trade Winds prevail for the major part of the year with speeds up to 50 km / hour. Cyclonic season last from

December to May. Gusts exceeding 250 km / hour may be experienced during the passage of strong cyclones.

Water resources are replenished every year during the wet season during the wettest months of the year from January to March. Even distribution of rainfall over the year is needed to maintain normal level in our rivers, reservoirs and aquifers. The distribution pattern of the long-term mean rainfall over the island is illustrated on Figure 1.

Figure 1. Long Term Average Rainfall over Mauritius (1971 – 2000)



PRECIPITATION TREND AND WATER RESOURCES AVAILABILITY

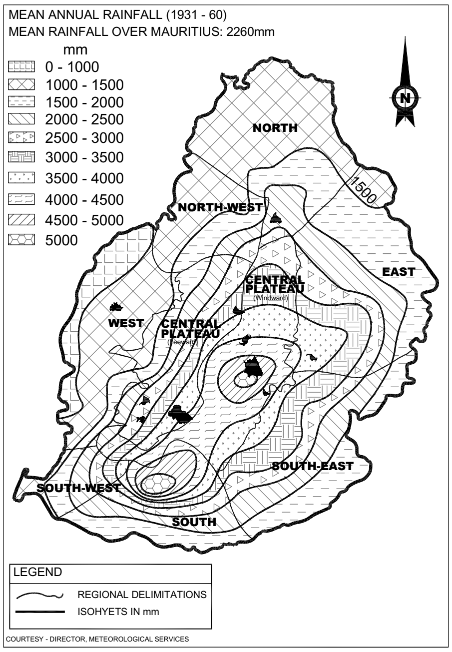
Trend in long-term mean rainfall

Statistical analysis of rainfall series for the period 1930-todate was carried out by the Mauritius Meteorological Services. The results may look alarming especially at a time where demand for water is increasing fast. Table 1 shows the trend.

Table 1. Trend in annual long-term mean rainfall over Mauritius

Period	Annual long-term mean rainfall (mm)
1931 - 1960	2260
1961 - 1990	2100
1971 - 2000	2000

Between 1930 and the present, average rainfall has decreased by about 12%. The real impact of this seemingly small decrease may be more important given that the recharge areas over high ground receive 1000 mm less annual rainfall. Isohyetal maps for periods 1931- 1960 and 1971 – 2000 show the changing rainfall pattern at Figures 2 & 3.



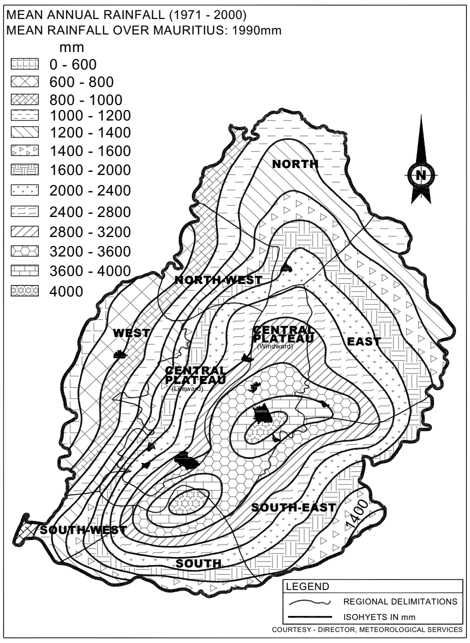


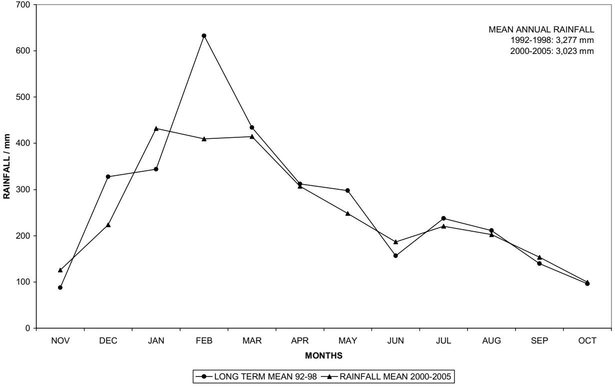
Figure 2. Mean Annual Rainfall over Mauritius 1931-1960

Figure 3. Mean Annual Rainfall over Mauritius 1971-2000

Drought in 1999 and post-drought changes

In 1999, the severe La NINA that occurred provoked large-scale air subsidence in the Indian Ocean Basin. This subsidence impeded convective cloud formation so much so that hardly any rainfall was received for months. The yearly rainfall fell to 50% of long-term mean.

Further studies show that after the drought in 1999, there is a shift in the onset of summer rains from December to January. The Central Plateau with the largest catchments in the common recharge zones, has seen a significant decrease in rainfall. Changes in rainfall pattern are shown for 3 rainfall stations. (Figures 4-6).



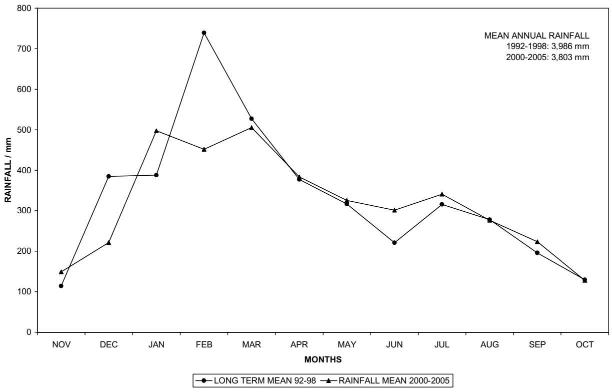
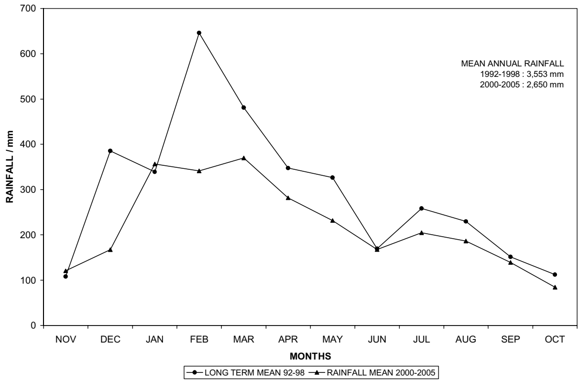


Figure 4. Mean Annual Rainfall for Belle Rive 1E

Figure 5. Mean Annual Rainfall for Arnaud

Figure 6. Mean Annual Rainfall for Piton du Milieu



River Flow Regime

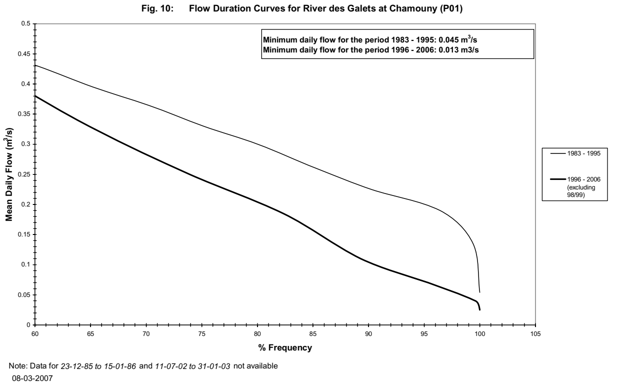
During the drought of 1999 the lowest river levels observed since 1972 were recorded. Figures are given for a few selected rivers in Table 4.

Table 4. Comparison of river flows

Name of River	Location and Code	Annual Volume Nov 1998-Oct 1999 (Mm^3)	Long-term mean 1972 - 1995 (Mm^3)	% of Long-term mean
Bel Air River Seche	Bel Air D01	8.0	55.1	14
Grand River South East	La Pipe E07 + E08aA	27.4	64.9	42
River Citron	Nouvelle France J01	5.5	12.3	45
River Galets	Chamouny P01	7.8	24.8	32
Cascade	Reduit W05	6.0	24.0	25
Calebasses	Calebasses Y02	2.6	17.3	15

Rivers with groundwater regime in some particular areas and as in the north of the island have been mostly affected due to absence of the recharging rainfall.

After the drought of 1999, problems were encountered in the supply adequate quantity of water to the population, especially from the direct river run off-takes in the Southern area of the island. Data for River des Galets, one of the rivers contributing to a treatment plant situated in the South, have been analysed in connection with the acute shortages of water. The flow frequency analysis on Figure 7 show drastic decrease in river flows. The 98% flow of 0.17 m^3/s observed in period 1983-1995 has fallen by 70% in the period 1996-2006 and the minimum daily flow from 0.045 m^3/s to 0.013 m^3/s. The decrease of annual volume in the above periods was about 18%.



Note: Data for *23-12-85 to 15-01-86* and *11-07-02 to 31-01-03* not available
08-03-2007

Figure 7. Flow frequency analysis for Riv. Des Galets

Prolongation of dry season and shortening of wet season is shown on Figure 8 and 9 for Bel Air River Seche and River Françoise (East).

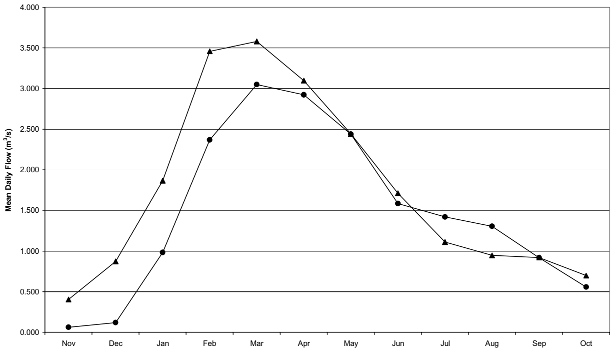


Figure 8. Comparison of monthly mean flows for Riv Seche at Bel Air (D01)

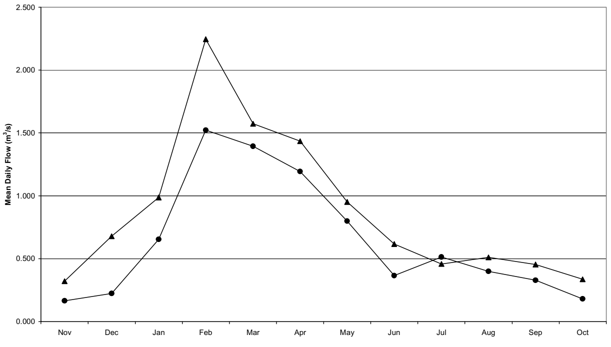


Figure 9. Comparison of monthly mean flows for Riv Francoise at Mt Maurice (E12)

GROUNDWATER REGIME

Aquifers are replenished and depleted on a yearly basis depending on rainfall distribution.

During the drought of 1999, groundwater production had decreased to a great extent. (See Figure 10). Changes in production level after 1999 have been detected in boreholes. A drop of 5,000 m^3/day on an average was observed at a borehole which is illustrated on Figure 11.

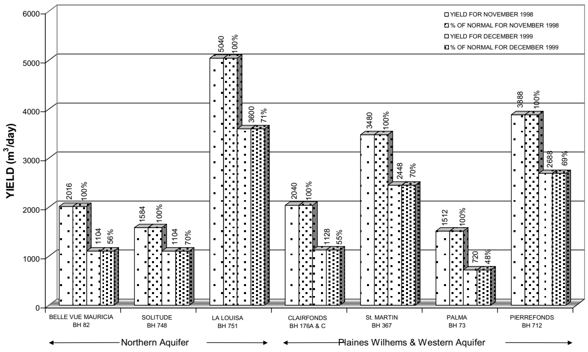


Figure 10. Groundwater production in selected boreholes in the North, Plaines Wilhems and Western aquifers

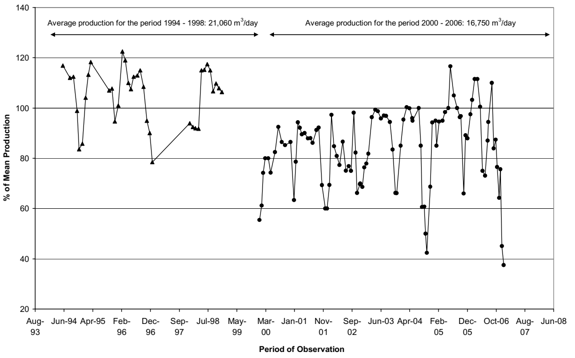
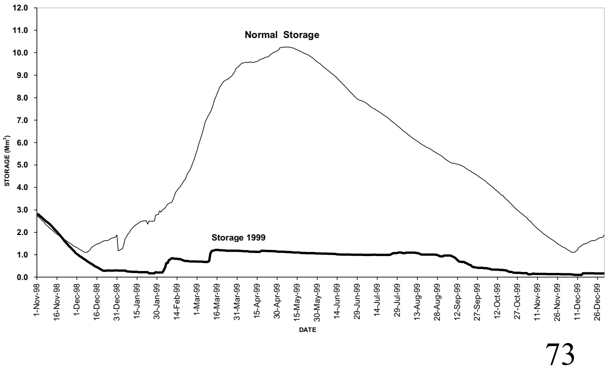


Figure 11. Groundwater production in boreholes at Hollyrood

Salt water intrusion in the coastal aquifers is being monitored at 22 locations. The equilibrium is still being maintained at the same level between fresh and seawater.

RESERVOIR MANAGEMENT

Reservoirs are replenished during the wet season. Depletion rate in other months is a function of rainfall input. During the drought of 1999 rate of depletion was dramatic in the reservoirs. (See figure 12 &13)



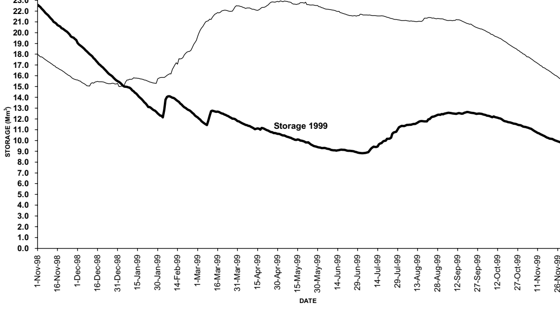


Figure 12. Normal and 1999 Storage curves for La Ferme Reservoir

Figure 13. Normal and 1999 Storage curves for Mare Aux Vacoas Reservoir

The lowest release from the biggest reservoir (Mare aux Vacoas Reservoir) used for domestic water supply was 40,000 m^3/day against a normal release of 90,000 m^3/day. Hardly any water was allocated for irrigation from the stored volumes. It has been observed after the drought that replenishment of reservoirs is starting later due to the shift of significant summer rain from December to January. Uneven rainfall distribution is causing disturbances to provide adequate water supply from the reservoirs. A 70% deficit in rainfall in the months of April and May 2006 had an adverse impact on water supply until the end of the year. This is displayed on Figure 14.

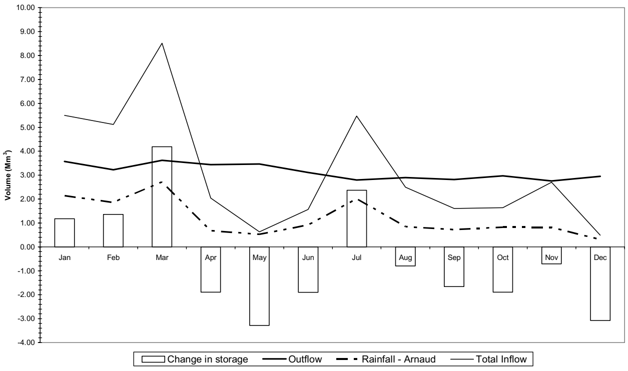


Figure 14. Water balance for Mare Aux Vacoas Reservoir for the year 2006

Management of reservoirs have become more challenging and requires closer monitoring of inflows and control of releases due to changing climate.

ADAPTATION TO CLIMATE CHANGE IN WATER RESOURCES MANAGEMENT

The adverse impact of climate change on the water resources is already felt due to decreasing trend and uneven distribution in rainfall pattern, occurrences of periodic droughts and prolonged dry seasons. Increasing demand for the economic development is exerting pressure on water resources also.

In order to mitigate the adverse impact of climate change, as described above, the following measures are proposed:

1) Close monitoring of water resources systems and coastal aquifers.
2) Periodical assessment of water resources potential.
3) Protection of common recharge zones of aquifers and rivers through appropriate land use management strategies including appropriate legal provisions.
4) Water recycling.
5) Reduction of losses in water distribution systems.
6) Water demand management.
7) Increase in surface water storage capacity.
8) Rationalisation of water rights for equitable and judicious use of water.

CONCLUSION

Climate is changing over the world "*Eleven of the twelve years in the period 1995-2006 rank among the top 12 warmest years in the instrumental record (since 1851)" {IPCC Fourth Assessment Report 2007}*and the small islands are the most vulnerable to it. Investigations conducted by the Mauritius Meteorological services have confirmed this for Mauritius as well. In fact average temperature has seen an increase of 0.8 deg Celcius between 1950 and the present. The last summer was the hottest of all so far. The Signs of the changes in the hydrological patterns that determine water availability have already been detected in Mauritius.

Water resources management need to tackle the challenges imposed by the changing climate in order to prevent water scarcity and to sustain development. *"Climate change is not a future threat, but a reality to which countries and people have to adapt."{UNDP, Human Development Report 2006)*

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Water resource management in Tibet and solution of data availability problems

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Keywords: Integrated water resource management, global changes, headwater river systems, hydrology, rainfall-runoff relationships, land cover.

ABSTRACT

Main objective of the paper is to explain the importance of the European – Asian cooperation in the area of the water management and address a harmonised integrated water resources management (IWRM) approach as defined by the European Water Initiative in headwater river systems of mountain massifs already impacted from climate change, and to establish transfer of professional IWRM expertise, approaches and tools based on case studies carried out in Bela river (Czech Republic) and Asian mountain river basins in Tibet (China). This is one of the possibilities of the solution of water management problems and uncertainties caused by the lack of data in the Tibetan Plateau.

INTRODUCTION

MOTTO: "To know the road ahead, ask those coming back."(an ancient Chinese proverb).

The impacts of climate change need to be studied and reviewed; this could prevent inconsistencies between climate change and environmental /socio-economic change and land cover scenarios. The land use and land cover have a significant influence on runoff characteristics in an area. This factor together with hydrosynoptical situation subsidiary influences a catchment's reaction on precipitation and water distribution. Type of land cover and its characteristics influence actual and long-term water balance of the land segment, in particular evapotranspiration, infiltration, surface and hypodermic discharge. Anthropogenic land cover changes often improve a retention ability of land **in negative way** thus complex water management has to count this factor. In the project "Application of Geoinformation Technologies for Improvement of Rainfall-Runoff Relationships", granted by Czech Academy of Science, the mountain Bela catchment was chosen as pilot area of the grant. The results of the project should be used not only for the Bela river basin itself, but as well for the modelling of the Rainfall-Runoff Relationships in the area of upstream part of the Brahmaputra (Yarlung Tsangpo) chatchment, in the Tibetan Plateau region, where **lack of data exists**.

The possibility of the use of the results was investigated during the field work conducted in the Tibet Antonomous Region in September 2006 (hereafter referred as Tibet) aimed to give the researchers the necessary appreciation for the water management issues and wetlands characterization in the area. The intention was also to investigate the state of water resource policy, legislation and define the methodology of the water and soil sampling and monitoring, on selected test sites. This work was financed by project BRAHMATWINN (of 6-th Framework Programme of EC).

TIBETAN PLATEAU

The Tibetan Plateau towers over the central part of the continent of Eurasia. It is bounded by the Himalayan mountain chain in the south, and connected with the Altyn Tagh and Gangkar Chogley Namgyal Mountains in the north. Its western part merges with the Karakoram Mountains and its eastern part slopes downward more gradually with Minyak Gangkar and Khawakarpo Mountains. Tibetan Plateau is the highest and largest plateau on the earth. The area occupied by the Tibetan Plateau is more than 2.5 million square km, its average elevation exceeds 4400 m and many of the peaks reach beyond 8000m. Based on natural topography, Tibet can be roughly divided into four parts, valley and drier regions in the south, plateau in the north, and high mountains with river valleys in the southwest and wet forest regions in the east.

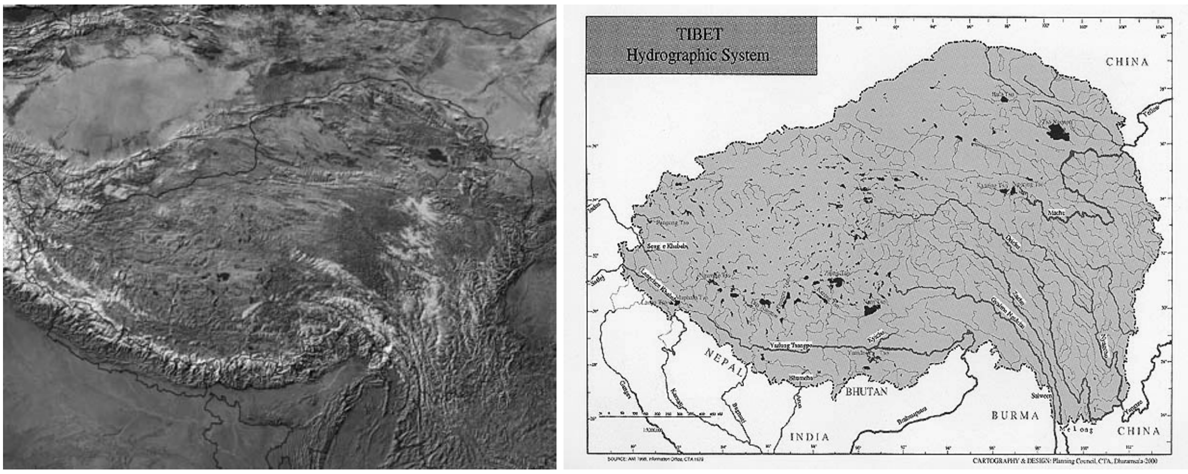

Figure 1: Map of Tibetan Plateau

The mountain area of Tibet Plateau is the sources of many great rivers in Asia. The hydrological net in Tibet is formed by **inner and outer river systems**. The inner rivers and streams usually run in specific seasons and form many lakes and ponds in the basins of the Plateau. The outer river system mainly rises in the east and southeast Tibet. Tibet is the principal source of ten major rivers of Asia: **Yarlung Tsangpo** (Brahmaputra), Satluj, Indus, Yangtze, Salween, Arun, Mekong, Karnali, Yellow River, Drukchu and numerous tributaries flowing into Asia. These rivers and their tributaries are the lifeblood of millions of people in the above continent.

Figure 2: NamCo

The rivers on the Tibetian Plateau are supplied by three kinds of water sources: rainwater and groundwater; rainwater, meltwater and groundwater; and meltwater purely. Our investigation in Tibet directed on the area of upstream of the Brahmaputra (Yarlung Tsangpo) and Lhasa rivers, as well as the holy lakes Nam-Co and Yadrok Yumtso. The Yarlung Tsangpo River is a typical example whose water supply relies on rainwater, meltwater and groundwater. Due to rainwater supply the river has more runoff and rapidly enters its high-water season with the beginning of the rainy season. At the same time, melting snow makes the water level reach an apparent peak. Usually a river has less volume of water during the winter and spring. However, since replenished by groundwater, the Yarlung Tsangpo does not have a marked lowest-water season.

In general, each year rivers on the Plateau begin to rise in April and May, reach the peak flood in July and August, and then fall gradually. From June to September is a river's flood season in which the water flow makes up over 60 % of the annual total flow. In July or August the volume of flow reaches its height, normally accounting for more than 25 % of the yearly flow on the southern Plateau. From November to next April is the dry season with the average monthly flow less than 5 % of the annual one. February has the minimum volume of water, only constituting l% to 2 % of the annual flow.

Every year, from April to June, there are the agricultural seasons of spring-sown crops on the Plateau. This short period demands large volume of water for use in agricultural production. **The contradiction between small flow of streams and a great amount of water-use is the main reason for spring drought occurring all over the Plateau**. An effective measure to combat spring drought is to artificially regulate the runoff of different rivers. In fact, regional differences in runoff fluctuation throughout the year are still great. For example, as far as the gorge rivers in southeastern Tibet are concerned, during the summer the flow makes up over 80 % of the annual runoff. However, in the spring the volume of flow takes less than l0 % of the yearly runoff.

The **distribution of surface runoff is very complicated on the Plateau** with varied natural conditions. On the southern slope of the Himalayas, especially from the great bend of the Yarlung Tsangpo River to the country's boundary line, the depth of the runoff is the greatest, reaching l000 mm to 2000 mm. Most of the Yarlung Tsangpo River valley is situated within the rain-bringing cloud belt on the northern Himalayas, with reduced rainfall upstream and a runoff depth between l00 mm and 300 mm. It is hard for the moisture to enter the Changtang Highland surrounded by high mountains, resulting in a runoff depth below 25 mm there. Based on distributive features of the yearly runoff depth all over the Plateau plus natural conditions, there are roughly four runoff zones: southeastern Tibet with abundant water resources, water-sick eastern Tibet, transitional zone in Nagqu, and Changtang with lack of water.

RIVERS

Yarlung Tsangpo River (Brahmaputra) has a total length of 1800 km, which main source is found in a great glacier-mass of the northernmost chain of the Himalayas, about 82° N. The river receives various tributaries in Tibet. Roughly speaking, the river may be said so far to run parallel to the main chain of the Himalaya at a distance of 100 km therefrom. The great river itself is known in Tibet by many names, being generally called the Nan Chu, Maghang Tsanpo or Yarlung Tsanpo, above Lhasa; the word tsanpo (tsang-po) meaning the pure one, and applying to all great rivers. An enormous development of agricultural resources has taken place within the Brahmaputra basin of late years, chiefly in the direction of tea cultivation, as well as in the production of jute and silk. Gold is found in the sands of all its upper tributaries, and coal and petroleum are amongst the chief mineral products which have been brought into economic prominence.

Kyi Chu River (Lhasa) originates from Nyangqentanglha Mountain on the Qinghai-Tibet Plateau and empties into the Yarlung Tsangpo River at Quxu. Lhasa is 551 km long and is one of the five major tributaries of the Yarlung Tsangpo. The drainage area of the river is nearly 30 000 km^2. (The well-known ancient city of Lhasa stands by the Lhasa River, located at the bottom of a small basin surrounded by mountains, has an elevation of 3650 meters and sits at 91°06’ E and 29°36’ N, in the centre of the Tibet Plateau). Lhasa river has an annual average daily temperature of 8° C and an annual precipitation of 500 mm. Lhasa is the only industrial town in Tibet with two major factories (manufacturing beer and footwear), which were built in the 1990s and which influenced negatively on the Lhasa river quality.

LAKES (in Tibetan language "co" means a lake)

Most lakes on the Plateau have their own distinct features. Usually a lake lies in the depression at the bottom of a valley or in the middle of a basin, with elevations of 4 100 to 4 900 meters. The Tibet boasts over 1 500 lakes of varying sizes, covering an aggregate area of 24 183 km^2. **The Nam Co stands as the largest inland lake in Tibet**, followed successively by the Seling Co, Zhari Nam Co, Damnoryungco and **Yamzhog Yumco**. The **Nam Co** at an elevation of 4718 meters covers an area of 1920 km^2: it is the inland tectonic lake subsidized by meltwater, bringing high mineralization to lake water. Nam Co water is salinized with a mineralization of 1.7 – 2 g/l (from which sulphates make more than 1600 mg/l). **Yamzhog Yumco** - 4,441 meters above sea level - lies south of the Lhasa River's outlet and has an average water depth of 30 to 58 meters. Yamzhog Yum (in Tibetan "coral”) has irregular shape and numerous lake arms and capes make the overall lake look like real coral.

Figure 3: Yamzhong Yumco

The mineralization or salinity of water in each lake in Tibet differs greatly. For example, some lakes in the southeast of the Plateau (like Yamzhog Yumco) have a rather low mineralization of 0.2 to 0.3 g/l, while on the interior Plateau some particular lakes like Namco reach a mineralization till about 300 g/l. Usually, with the rising mineralization, the content of sodium, potassium and chlorine ions in saltwater is going up accordingly, while the content of magnesium and sulphates rises rather slowly and that of calcium and carbonic acid ions changes very little. Fresh water essentially contains double calcium carbonate, while salt lake water contains sodium chloride mostly.

GLOBAL CLIMATIC EFFECTS AND WATER RESOURCE POLICY & LEGISLATION IN CHINA

Tibet, because of its immense geographical position and height, considerably influences the global weather pattern by affecting the flow of jet streams over the Tibetan Plateau. Loss of forest and grassland cover of the Plateau will affect the jet stream pattern, which will affect pacific typhoons and also cause the el nino effect which altogether affect the weather pattern of Europe, USA, Mexico, Peru, India, China and other adjoining areas to affect their economy.

The state owned water resources in China is governed by institutional and regulatory arrangement; both at national and local levels. At the national level, the Ministry of Water Resources performs its administrative authority on water resource management and is more quantitatively focused, while the State Environmental Protection Administration takes charge of aquatic environmental protection. The responsibility distribution is under the institutional arrangement in the State Council, and it is also

stipulated and maintained by laws enacted by the National People´s Congress – namely the Water Law (2002) and the Law on the Prevention and Control of Water Pollution (1996).
However, the water-related laws and institutions are not working effectively in the Tibet. The naturally integrated water system is functionally divided into different parts and it is leading to the segmentation of surface and ground waters, segmentation of quantity and quality and segmentation of rural and urban water management. Even though the Tibetan Plateau is regarded as the "Water Tower" in Asia, which might have partially relieved the local water issues, it becomes more and more clear that weaknesses in the institutional arrangement have led to management failures. For example: the groundwater in Lhasa is reported to be declining, increasing the costs of withdrawing water and threatening safety. However in Central Tibet only Lhasa has any garbage disposal plant. Major towns including Shigatse, Tsethang, Chamdo, Nagchu and Gyantse, have no method of handling garbage disposal. In a broader view of the political background, the **water management is not strategically prioritized in Tibet**, in the master plan of economy and social development and mostly created for investment-centered development.

WATER RESOURCE MANAGEMENT

Water pollution in China is a major problem and although the water quality of the water courses in Tibet is not affected to the huge extent yet, the signs of decreasing water quality are already apparent. There is lack of a formal waste and sewage removal systems in Tibet, even though the local economy is growing quickly. The sources of contamination are varied: agricultural, human, animal wastes as well as mining waste products. Copper, gold and chromites are the major mining activities and tailing from these mines are not treated before they get disposed of in rivers. Sulphuric acid, cyanide and heavy metals are the mail pollutants expected to be in Tibet.
Other water resource management problem seems to be issues as: the increasing development in irrigation requirements, hydropower developments and the deforestration in the mountainous areas; the impact of medium-sized dams in the catchments is also starting to become a significant issue by increasing river fragmentation (for example: Yarlung Tsangpo catchment). In the Lhasa catchment, the sudden intensification of grain production relies on heavy applications of chemical fertilisers and pesticides to achieve yields, which in turn leads to chemical pollution of the Yarlung Tsangpo. China's 2003 white paper admits to the presence of persistent organochlorine compounds in this fertile region, saying only that the problem is now being monitored and surveyed without outlining any remedial measures. Our investigation in the September 2006 did not found any dangerous contaminants in the surface and ground waters in the area, yet.
However, the field experiences from Tibet and discussion related to licensing and pollution control, as well as water conservancy, flood and drought control proof, that **IWRM within the Tibetan Plateau is not exist**. Usually, most of the water related problems are solved through engineering solutions, without due consideration for the sustainability of the measures.

RESULTS

Open grasslands (typical land use pattern in Tibet) - accounting for more than 60 % of the landmass of Tibet - have sustained Tibetan pastoral herds over the millennia. Today there is expert consensus that Tibet's grasslands are degrading and that this is having serious consequences on the livelihood of Tibetan nomads as well as **affecting climate patterns for China and the world.** As we have seen in September 2006, the following factors have significant impact on massive grassland degradation:

- conversion of grassland to cropland (in the Great Leap Forward of the early '50s) and since then abandoned and not used as cropland or grassland, now
- reclamation of communal land, the traditional pastures of semi-nomads, under a new policy to allow commercial development
- uncontrolled mining
- uncontrolled infrastructure (highways, railroad tracks, etc.) development
- elimination of indigenous predators and change of the ecosystem
- undermining of the role of traditional Tibetan community-based management of grassland.

The environmental damage to grassland was done by a government policy aimed domiciliation of nomads. Undermining the role of Tibet's nomads has resulted in a grassland crisis as real as the dilemma faced by tropical rainforests. The combined impacts of erosion, fencing, sedentarisation, debt, poverty, taxation, toxic weed invasions, soil loss, exclusion and the absence of basic human services threatens the very survival of the nomadic way of life. **Pastoral-friendly policies and long-term Water Resource Management are urgently needed.**

DISCUSSION AND CONCLUSIONS

The above logic is driving development, water management and environment policies currently imposed from afar on Tibet - be it the settling of nomads, fencing of grassland, changing quality/quantity of he waters, reforestation, infrastructure development, urbanisation and the approach towards sustainable development. The Tibetan preference will always be for **environmentally sustainable small-scale projects** that directly meet basic human and environmental needs. Large-scale projects, especially heavy infrastructure and industry, are not suitable development investments for the Tibetan Plateau. **To proof such approach, the model scenarios are necessary, to convince the decissionmakers and stakeholders about the right steps.** We must know the real conditions of the water management issues and model the consequences of anthropogenic land cover changes to predict the future of the nature of the Tibetan Plateau, the Asia and the world.

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Climate change impact on mean annual river flows

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ABSTRACT

Analyses of mean annual flow data for major Slovene rivers (Sava, Drava, and Mura) have been derived for the last thirty or sixty years, respectively. In the past twenty years, significant trends in decreasing flows have been identified. Trends in water balance were also analyzed by Wat Bal model. Similar trends have been observed on other European rivers (Rein) and US rivers (Colorado).

INTRODUCTION

Mean annual river flows present a water balance of watersheds, and these are important for water management and water use. These are also, good indicators of climate variability in the past century, if there are no significant impacts of water use for irrigation. However, increasing temperatures and decreased moisture supply requires increases in irrigation for crop vitality. Qian, et al (2006) examined annual discharges from the world's 10 largest rivers and compared results with CLM3 model simulations for the period from 1948 to 2002. Their time series showed a variety of results from clear trends of declining discharge from 1995 to 2004 in the Columbia (US), Congo (Africa), Changjiang (China), Mississippi (US), Lena (Russia), and Parana (S. America) to no apparent trends in the Amazon (Brazil), Orinoco (Venezuela), Yenisey, Severnaya Dvina (Russia), Susquehanna (US), and Gota (Sweden).

River flow variations depend on the precipitation and evaporation as input in the watershed system, and water storages in the watershed that represent a stage of the system. Variations in the input of the watershed system multiply the variations of river flow as output from watershed system. Percentage of the variation in yearly flows is higher than percentage of the variation in precipitation, considering same stage of the system, Kobolod and Sušelj (2005). Those variations are significant and characterize particular watershed.

The stages of the watershed system normally are lowest at the end of hydrological year (end of September) rather than at the end of calendar year, but data of annual flows collected in many data bases are mainly related to the calendar year. Water managers use the data for Water Years (WY) from 1 October to 30 September.

Hydropower production is highly dependent upon water supply, thus large variations in flow will have significant economic impacts on energy production. Water use and water management are also highly dependent on annual variations. These impacts are stronger in areas where water use is fully developed, or even over allocated, as in the Western United States. Here today, variations in annual flows have large impacts on water use, water rights, and may even limit allocations for environmental protection of endangered species. Competition among consumptive use by agriculture, people, and environmental needs becomes critical in periods of drought, hence long-term planning for water conservation and storage systems is needed.

METHODS

The annual flows are analysed on calendar year basis as they were received from relevant data bases. Data for hydrological year should be recalculated on from monthly flow data that are not always available. Data for the Colorado River basin was recalculated as natural flows, because surface water storage and water use has tremendous impact on the measured river flows in the fully developed watershed system of the Colorado River (Matthews et al 2000, Christensen et al 2004).

Data are simply arranged according to ten-year moving averages and trends are calculated and plotted for different samples and part of the samples. Water balance of the Sava River studied in the detail and trends in the samples of input data and calculated data are presented.

Water balance of the Sava River were studied by semi-distributed water balance model WatBal. Wat Bal was derived in 1970s as lumped model in sub-alpine areas (Leaf and Brink, 1975). Later it was developed and expanded for use not only in water balance modelling, but also for calculation of water quality, sediment transport and climate change impacts. Modified version of the model was used for modeling of water balance of Danube River Basin (Petrovič et al, 2005, Yates, Strzepek, 1994). With model WatBal we looked for the best fit regard as the tuning criteria, which should be as close as possible to zero. Calibration parameters set in following order are ATSNOW (temperature for the evaluation of snowfall), ATRAIN (temperature for evaluation of rainfall), WSFFC (soil moisture content in the balanced top layer – fine tuning), WCRIT (critical soil moisture content), MGDFAC (melting factor) and PRIESK (fast infiltration coefficient). The calibration is done when the three tuning criteria are minimised. (Petrovič et al, 2005). The model was used for more detail calculation of the Sava River Basin in Slovenia.

SAVA RIVER BASIN

The Sava is a right side tributary of the Danube River at Belgrade. In Slovenia the Sava drains an area of 10.764 km², which is 53% of Slovenian territory. For Sava was made the water balance model (WatBal) as part of a project Basin – Wide Water Balance in the Danube River Basin Petrovič et al, 2003). The input meteorological data for model are runoff depth, monthly precipitation totals, monthly means of air temperature and monthly means of air humidity. For the purpose of potential evapotranspiration estimation it is necessary to define zones of basin, which are defined by height of the terrain. The basin in Slovenia was divided into two parts controlled by water station Litija and Čatež.
Later on we divide Sava river basin in twelve zones, Figure 1. At the beginning of flow the Sava is created by two headwaters, Sava Dolinka (left) and Sava Bohinjka (right) which join between the Slovenian towns of Lesce and Radovljica. The Sava Dolinka (area 501 km2) starts in the Planica Valley and goes underground and breaks out again near Kranjska Gora. The Sava Bohinjka (area 387 km^2) originates under the Komarča Ridge from underground sources drained from the Triglav Lakes Valley.

First two left tributaries of Sava are Tržiška Bistrica and Kokra, which zone is named Sava – Kranj in model (area 640 km^2). First right tributary is Sora (area 647 km^2), which has a mountain nature. The Ljubljanica river some 20 km of its course lies underground in caves, so the river has seven names. Area of Ljubljanica river basin is estimated at 1.883 km^2. The Ljubljanica is a right tributary of the Sava, with the confluence of the three rivers lying about 10 km downstream from Ljubljana. The third river at confluence is a left tributary Kamniška Bistrica (area 657 km^2), which is an Alpine river in northern Slovenia. East of Ljubljana, the Sava flows through a 90 km long gorge and afterwards the Krško Field. This zone of Sava basin is in model named as city it crosses – Litija and measures 523 km^2. Afterwards there are two tributaries divided in two parts: left tributary Savinja river is in model divided on zones Celje (area 1.193 km^2) and Veliko Širje (area 660 km^2) and right tributary Krka, also divided in two zones Dvor (area 1.105 km^2) and Podbočje (area 1.145 km^2). The Savinja (area 1.853 km^2) is a river in north-east Slovenia and flows mostly in the Upper and Lower Savinja valley. It flows into Sava River at Zidani Most. The Krka (area 2.250 km^2) originates around 25 km south-east of Ljubljana, before flowing south-east to meet the Sava at Brežice near the Croatian border. Zone between the left and right tributary is in model named Čatež and it measures 757 km^2. Data of the watershed charatcteristics are in the table 1. Watershed is mainly covered by forest 68%, agricultural land 28%, urban area only 2% and surface water less than 1%.

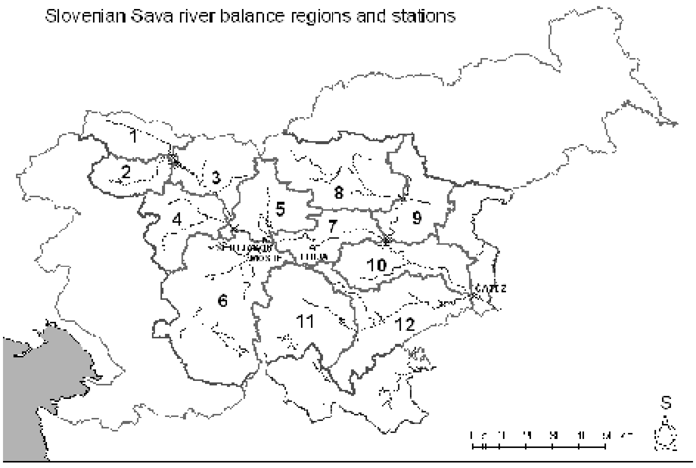


Figure 1. Sava River Basin with WatBal regions

Table 1: Land surface characteristics of the Sava River subwatersheds, CORINE land cover

	percentiles					area in square kilometers				
HO_	Total_(%)	urban	agric.	forest	water	Total	urban	agric.	forest	water
1	100	2,45	9,81	87,62	0,12	501,52	12,29	49,18	439,42	0,62
2	100	0,80	9,04	89,00	1,17	387,11	3,09	34,99	344,52	4,51
3	100	4,26	23,03	72,47	0,23	639,91	27,28	147,40	463,77	1,45
4	100	2,43	27,09	70,48	0,00	648,13	15,76	175,58	456,79	0,00
5	100	6,08	35,38	58,31	0,23	656,69	39,94	232,35	382,88	1,52
6	100	5,12	27,31	66,28	1,28	1884,58	96,58	514,70	1249,14	24,17
7	100	3,10	27,15	68,82	0,93	523,72	16,22	142,19	360,41	4,90
8	100	1,20	30,83	67,77	0,20	1105,46	13,32	340,83	749,14	2,18
9	100	2,36	48,37	48,89	0,37	659,73	15,60	319,10	322,57	2,46
10	100	1,56	43,68	54,05	0,71	757,32	11,81	330,80	409,30	5,41
11	100	2,92	30,73	65,99	0,36	1193,13	34,80	0,00	787,37	4,27
12	100	1,77	38,47	59,32	0,44	1144,55	20,26	440,31	678,98	5,00

RESULTS

The WatBal model for Sava River basin was calibrated for period of 41 year from 1960 to 2000. Linear trends and ten year moving average was also calculated for the period, fig. 2. There is very well recognized descendent trend of discharges for all the period of calculation. The reason for descendent trend in discharges is in the decreasing of the precipitation and slightly increasing of evaporation, fig. 3a. The descendent trend is also not so clear on the all of subwatersheds, figures 3b.

The Sava River watershed at water station Šentjajob has a mountainous area 2.176 km^2 in surface and the Ljubljanica River has karst watershed with 1884 square kilometers of area at water station Moste. The Rivers have similar watershed areas but large differences in water regime. Ten-year moving average of the measured discharges for the stations on the Sava River are in the fig. 4. Discharge drops down significantly on the Sava River in the past forty years. The trend is signifacntly lower in the past twenty years, and there are some tributaries as the Ljubljanica River that have steady trend of discharges in the past twenty years.

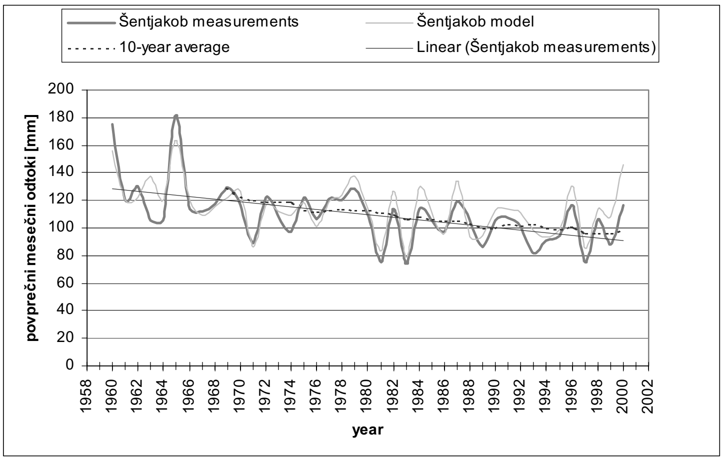
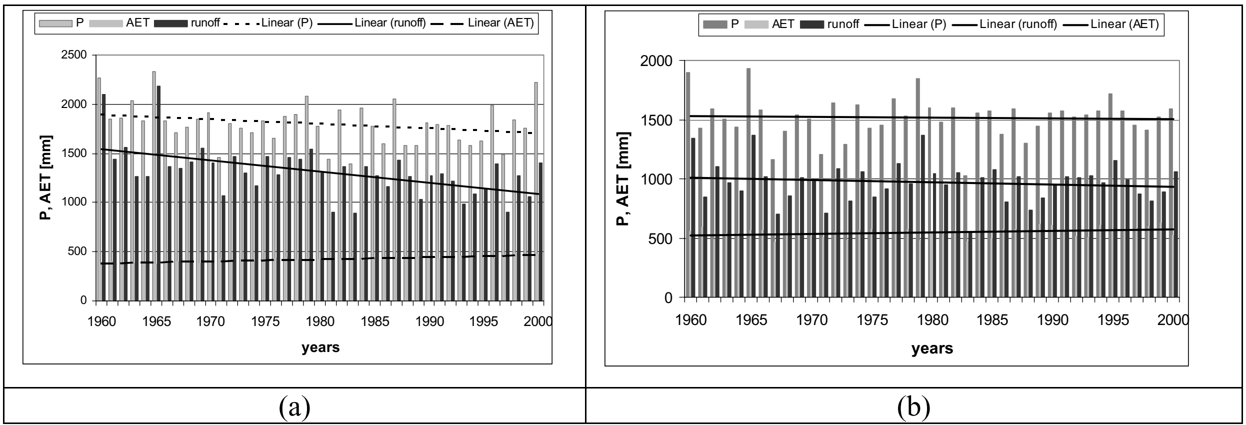


Figure 2. Measured and validated discharge of the Sava river at water station Šentjakob



(a) (b)

Figure 3. Water balance of the Sava River at water station Šentjakob (a) and Ljubljanica River at water station Moste.

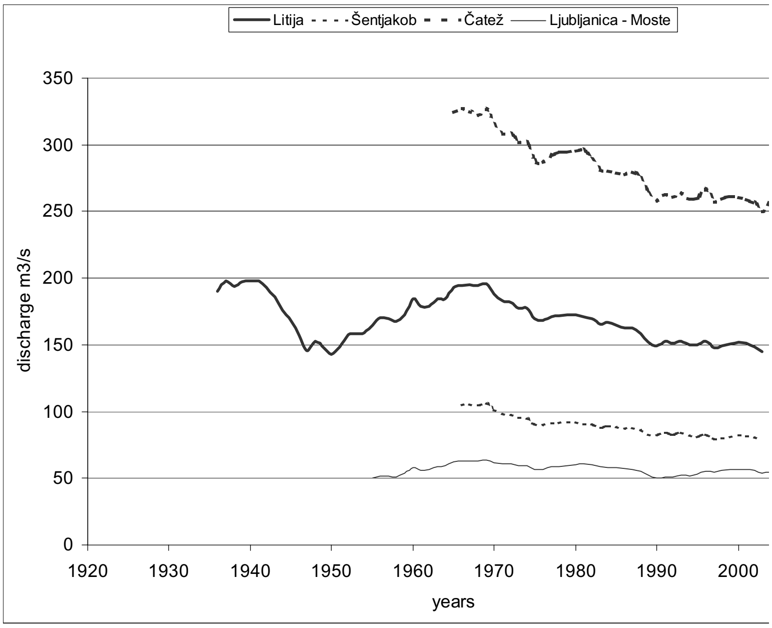


Figure 4. Ten-year moving average of the discharges on water stages on the Sava River

The ratio of discharge relative to mean in period 1961-1990 calculated for Sava River, Mura River, Colorado River and Rhine River, fig.5. The Mura River with headwaters in the Austrian Alps has a significant rise of discharge in the past thirty years. Rhine river with headwaters in the Swiss Alps has significant rise of discharges in past fifty years, also surpassingly regime of the Rhine River differentiates very much from regime of the Mura River.

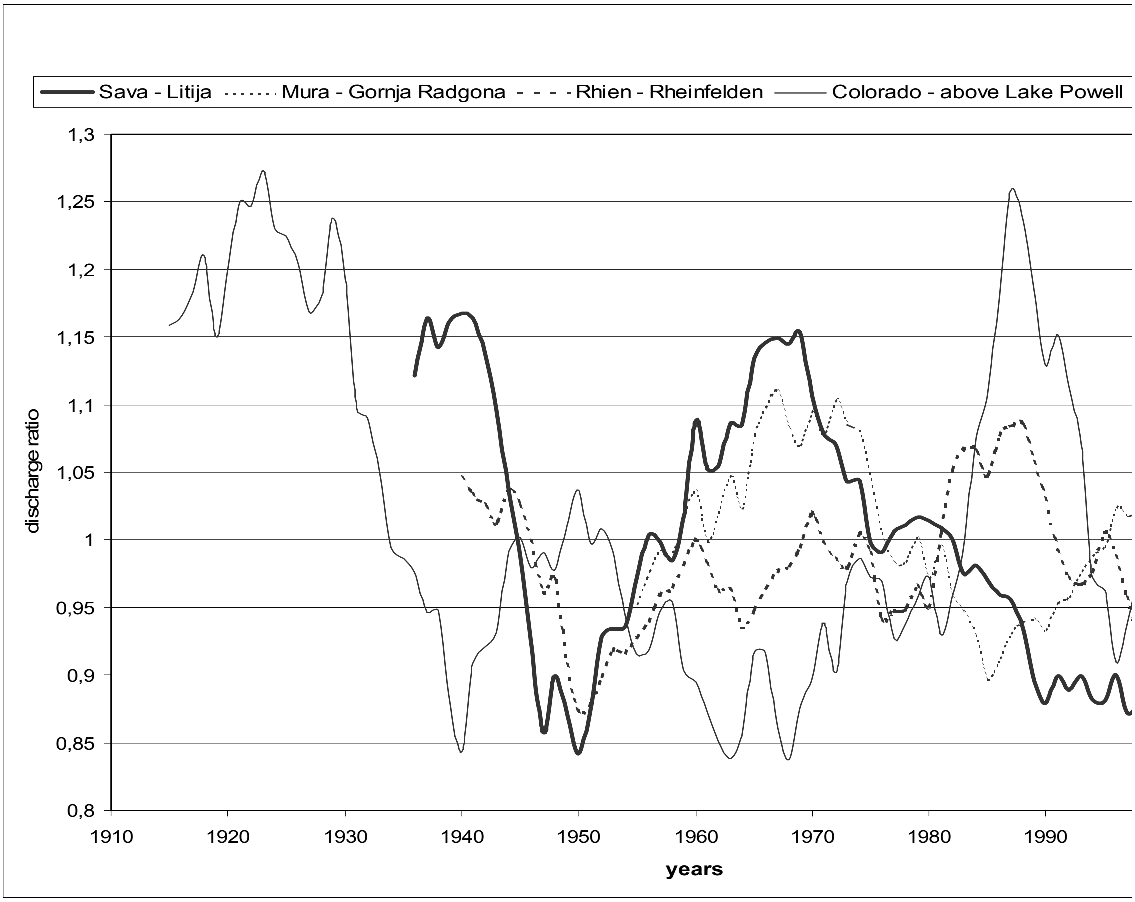


Figure 5. Ten-year moving average of discharge ratio (annual discharge/mean discharge from1961-1990)

Analyses of the Colorado River Natural Flow data show that during the past 20 years there have been large variations in extremes from floods to drought conditions. During the past 10 years the river system has been in extreme drought conditions with reservoirs now less than 50% of capacity. Figure 5, shows the annual WY discharge of the river (series-1) with 10-year moving averages showing the trends in natural variations. Winter snow pack provides over 80% of the water supply for the Colorado. Warmer and dryer winters have decreased the total water supply and shifted the melt and peak runoff earlier in the Spring. Matthews et al (1992) and Dettinger et al (2001) have noted this trend in many western US river basins. The Colorado River has also highest fluctuation in water regime. Suprisingly Colorado River (from arid regions) and Sava River (moist regions) have highest variation in comparison to Rhine and Mura Rivers.

DISCUSSION AND CONCLUSIONS

There are no clear universal trends in the water regimes of the analyzed rivers in the past century or in past twenty years also. Large differences in trends occur even in nearby watersheds. Similarity is presented in the discharge regime along the river stream.

Also fluctuation of the discharges related to average differentiate between rivers and there is no high difference between humid and arid climate, also there is no difference in amplitude in the past century and past thirty years. The Sava and Colorado Rivers have long periods when their discharge is below the long term average discharge. This below normal trend appears to be increasing during the past 10 years. If this trend continues, it will have significant impacts on water supplies, hydropower generation, agriculture, and availability of potable water for municipal use.

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Pan-Arctic drainage basin monitoring: current status and potential significance for assessment of climate change effects and feedbacks

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Keywords: arctic, hydrology, monitoring, water chemistry

ABSTRACT

Access to reliable hydrologic data is of paramount importance for accurately understanding and modeling ongoing change in and climate feedbacks of the Arctic hydrologic cycle. The accessibility to such data is limited, and continues to decline for some Arctic areas, but there is little information on where and which data gaps are most critical. We present a quantitative assessment of openly accessible monitoring data for water discharge and chemistry in the pan-Arctic drainage basin. We also quantify differences in characteristics between monitored and unmonitored areas, and analyze spatial patterns in reported decline of discharge networks in relation to recently observed and future modeled temperature trends. Results indicate that there is significant disparity in the spatial and temporal distribution of monitoring data, in particular for water chemistry monitoring. Additionally, there are systematic differences between the characteristics of monitored and unmonitored areas, within and between the different continents in the pan-Arctic drainage basin. Discharge network density has declined the most in four Eurasian drainage basins, which show the smallest recently observed temperature trends but the greatest modeled future temperature changes. Differences in characteristics between monitored and unmonitored areas may limit the reliability of assessments of Arctic water and solute flux change under a warming climate. Arctic monitoring needs to be extended in certain areas to fully enable characterization of the hydrologic variability and change in the region.

INTRODUCTION

The hydrologic cycle plays a key role in the Arctic environment, and offers an excellent theme for exploring the linkages between different components of the Arctic system (Vörösmarty et al., 2001). In recent decades, this system has been subject to significant changes, such as declining extent of sea ice (Stroeve et al., 2005), shorter extent of snow cover season (Serreze et al., 2000), rising average temperatures (Serreze and Francis, 2006), increasing river runoff (Peterson et al., 2002) and increasing precipitation (Houghton et al., 2001). To better understand the interconnections between these transitions, access to reliable environmental data is of paramount importance. Unfortunately, the harsh climate, long distances and low population density limit the availability of monitoring data for the Arctic. Recent discussions of the global status of hydrological monitoring programs (Brown, 2002, Maurer, 2003, GCOS, 2005) paint a mostly bleak picture of the situation today—stations are being closed; data is delayed, incomplete or not disseminated. The situation in the Arctic is also worrying (Lammers et al., 2001, Shiklomanov et al., 2002, Walsh et al., 2005). Despite these difficulties, significant efforts have been made to harmonize and make accessible Arctic discharge data (e.g., Lammers et al., 2001, GRDC, 2006, ArcticRIMS, 2007). However, in order to quantify mass fluxes of carbon and nutrients, water chemistry monitoring, used in concert with discharge monitoring, is crucial. Unfortunately, such data for the Arctic region are even less prevalent than runoff data (Holmes et al., 2002, Prowse et al., 2005).

Focusing on areas draining to the Arctic Ocean, the present study aims to establish a quantitative picture of the current status of openly accessible discharge and water chemistry monitoring, to characterize the main properties of monitored and unmonitored areas and to analyze patterns in the reported decline of monitoring network density in light of past and projected future climate change.

METHODS

Openly accessible monitoring data for discharge was gathered from the established international discharge databases of the Global Runoff Data Centre (GRDC, 2006), the Regional, Hydrometeorological Data Network for the Pan-Arctic Region (R-ArcticNET; Lammers et al., 2001) the Arctic Rapid Integrated Monitoring System (ArcticRIMS, 2007) and the Global River Discharge Database (RivDis; Vörösmarty et al., 1998). Water chemistry data were assembled from various databases, based on information in the metadatabases of the National Snow and Ice Data Center, the ACSYS Data and Information Service, the Global Observing Systems Information Center and the Global Runoff Data Center. The accessible water chemistry parameters were grouped into the categories carbon, nitrogen, phosphorus and sediment. For all monitoring programs, datasets were processed to summarize records of series length, first operational year and latest available data year for each station. Stations with no coordinate information or no data available were removed.

Monitored and unmonitored catchment areas were identified by co-referencing monitoring stations to the 30 × 30-minute STN-30p drainage network (Simulated Topological Network; Vörösmarty et al., 2000). Stations with a drainage area representing less than 5 cells were removed. All stations with a difference of more than 10% between listed and simulated drainage areas were manually inspected, and subsequently either deleted or relocated, with aid from the Hydro1k river network at 1 × 1 km resolution (U.S. Geological Survey, 1998). Finally, maps that show the maximum length of data series, and last data year accessible, for all parameters were produced.

To identify potential biases in monitoring representation of hydrologic properties, quotients between the area-weighted distribution of vegetation zones, built-up land, permafrost, population, economic production, snow depth, soil organic carbon, soil moisture, and distance to ocean were calculated for unmonitored and monitored areas in North America, Europe and Asia. Vegetation zone data were based on the World Wildlife Fund's Terrestrial Ecoregions (Olson et al., 2001). The built-up land data were compiled by Miteva (2001), and permafrost information was taken from International Permafrost Association data (UNEP/GRID-Arendal, 1998). For calculation of population and population density, the Gridded Population of the World database (Center for International Earth Science Information Network, 2005) was used. Economic production data were based on the G-Econ (Geographically based Economic data) database (Nordhaus et al., 2006). Average annual snow cover, soil carbon and soil moisture, based on climatologies for the period 1950-1999 (Wilmott and Matsuura, 2001) were taken from the Atlas of the Biosphere project, University of Wisconsin. The distance to ocean information was based on data from the STN-30p drainage network (Vörösmarty et al., 2000).

In order to study whether reported decline in discharge monitoring station density has any important bias with regard to climate change, an analysis of the station density changes in the GRDC program was compared to observed present and modeled future temperatures for a range of Arctic drainage basins. The fraction of GRDC stations with accessible discharge data for the relatively recent period of 1995-99 was calculated relative to the corresponding number of stations for the period of 1975-79, to illustrate how the station density of today compares to that during the period of peak monitoring density during the 1970s. Recent observed temperature trends for 1995-2002 were obtained by combining gridded data sets CRU CL 1.0 (New et al, 1999) and CRU TS 2.1 (Mitchell and Jones, 2005). Future temperature change fields for the 2020s, relative to 1961-90, were acquired from the IPCC Data Center (IPCC, 2007) and averaged for three Global Circulation Models (CCC, ECHAM and NIES) and the SRES (Special Report on Emission Scenarios) A2a scenario. Furthermore, the range in value between the different models was calculated as a measure of the degree of uncertainty in predictions.

RESULTS

Five databases with accessible water chemistry monitoring data for Arctic regions were identified. These are GEMS/Water (GEMStat, 2007), Eurasian River Historical Nutrient and Sediment Flux Data (Holmes and Peterson, 2002), HYDAT (Environment Canada, 2004), European Environment Agency

(European Environment Agency, 2007) and the USGS National Water Information System (U.S. Geological Survey, 2007).

Figure 1 shows an overview of the spatial and temporal extent of monitoring of water, carbon, nitrogen, phosphorous and sediment fluxes. It shows that the accessible discharge data are vastly more extensive, both spatially and temporally, than water chemistry data. However, even discharge monitoring covers no more than 66% of the area draining to the Arctic Ocean. Nitrogen and phosphorus monitoring cover 47% of the Arctic Ocean drainage, sediment monitoring covers 44%, and carbon monitoring covers only 7%.

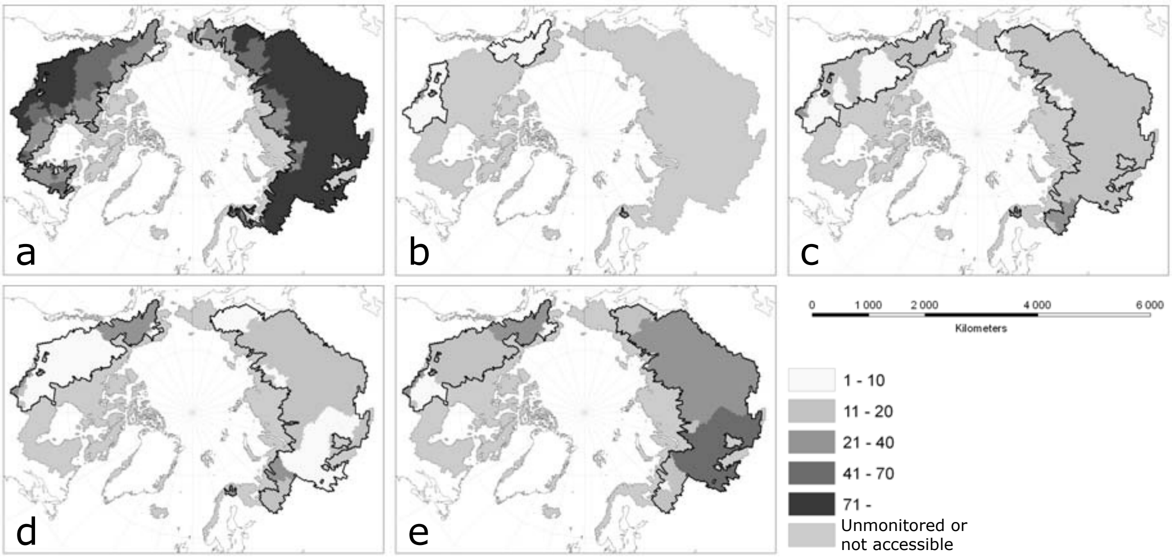

Figure 1. Maximum length of accessible data series (yrs) for pan-Arctic monitoring of (a) discharge, (b) carbon, (c) nitrogen, (d) phosphorus, and (e) sediment. Lambert azimuthal equal-area projection.

CHARACTERISTICS OF MONITORED AND UNMONITORED AREAS

Figure 2 summarizes the differences in area-weighted characteristics between unmonitored and monitored areas for the continents in the pan-Arctic drainage, and for different monitoring parameters, expressed as quotients between area-weighted average values of the studied basin properties. For characteristics related to anthropogenic impacts (population density, average gross cell product and built-up land), North America systematically exhibits the lowest quotients between unmonitored and monitored areas, and monitored areas in North America are therefore the most biased towards excluding population- and production-poor catchments. In contrast, accessible European carbon monitoring is biased towards including these population-poor, and also ocean-close, catchments. Asian monitoring quotients generally lie between North America and Europe in the balance of anthropogenic pressures. With respect to vegetation zones, boreal forests and taiga are underrepresented in unmonitored areas, particularly in Asia. Temperate grasslands are much more prevalent in monitored than unmonitored areas in North America, while their occurrence is balanced in Asian monitoring. Tundra and continuous permafrost are strongly overrepresented, and average annual snow depth is much greater, in unmonitored areas on all continents. Soil carbon and moisture are the most well-balanced characteristics, even though the quotient between unmonitored and unmonitored areas for these parameters can still amount to more than ±20%.

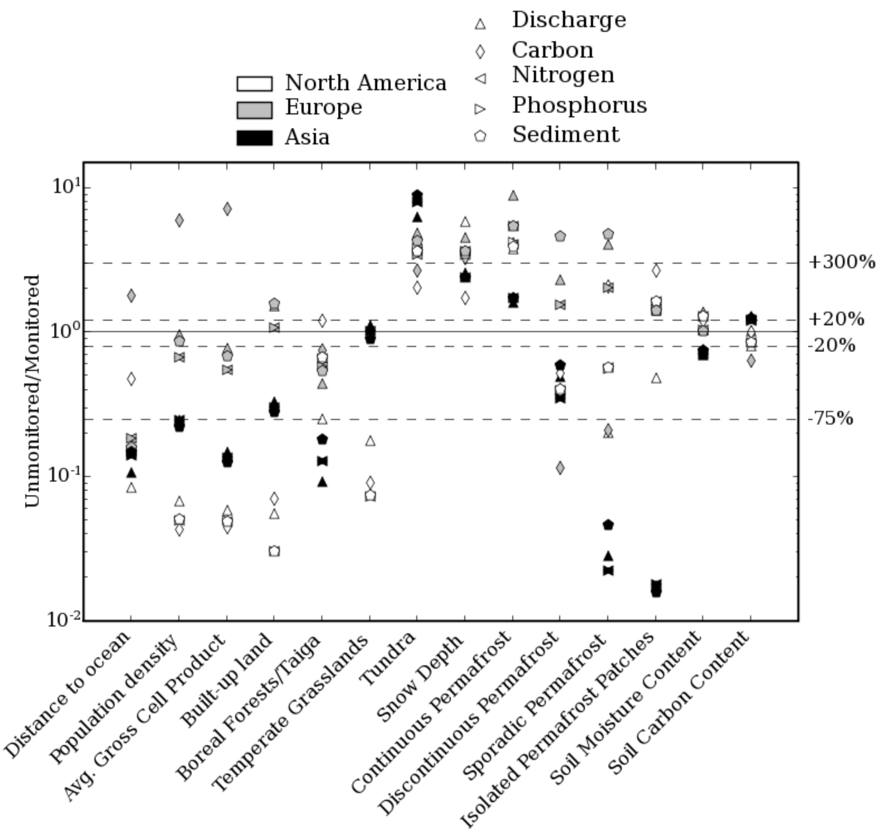

Figure 2. Quotients of area-weighted average characteristic values between unmonitored and monitored areas, with respect to discharge, carbon, nitrogen, phosphorus, and sediment, for different continents in the pan-Arctic drainage.

CLIMATE-SENSITIVE MONITORING AREAS

In figure 3 we show how the decline in discharge monitoring relates to recently observed and modeled future temperature trends. Four Eurasian drainage basins – draining into the Barents, East Siberian, Laptev, and Kara Seas – have been subject to the greatest absolute and relative decrease in discharge monitoring density in the GRDC database (figure 3). The difference between the number of stations with data accessible for the two periods are -243, -63, -134, and -520 stations for these four drainage basins, respectively. With respect to observed climate trends during the period 1995-2002, the smallest temperature change so far has occurred in the four drainage basins with the most significantly decreasing monitoring density (figure 3, left). However, the pattern is reversed in modeled future temperature trends. The four drainage basins with the most pronounced decline in discharge monitoring density are also the ones that are expected to have the greatest future temperature change (figure 3, right). The absolute range, i.e., the uncertainty of modeled future temperatures, is also particularly large for these four areas.

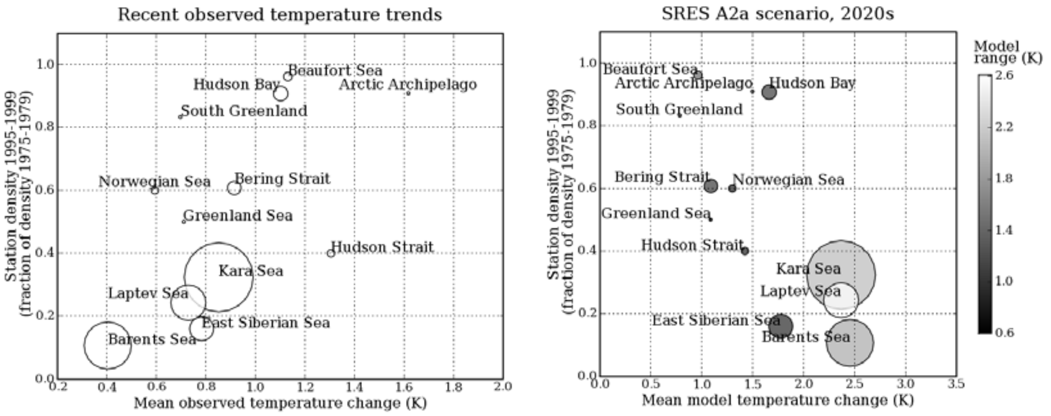

Figure 3. Evolution of discharge monitoring station density in Arctic drainage basins, from the period 1975-1979 to the period 1995-1999 (vertical axis), in relation to the observed temperature increase in 1995-2002 compared to 1961-1990 (horizontal axis; left) and the GCM-projected temperature change fields for the 2020s (horizontal axis; right). Circle sizes correspond to the absolute reduction in number of discharge monitoring stations with accessible data. On right, circle colors represent the range in mean projected temperature by the three different GCMs (CCC, ECHAM and NIES).

DISCUSSION AND CONCLUSIONS

The limited coverage of water chemistry monitoring implies that climate-effect and environmental modelers, as well as policymakers and public, have restricted ability to correctly assess ongoing changes transforming the Arctic environment. In particular, the discrepancy with the accessibility to published discharge data means that important budgets of carbon, sediment and nutrients cannot be closed for large areas of the Arctic. The shorter time series, restricted accessibility to recent data and limited spatial coverage of water chemistry measurements therefore hampers efforts aiming at improving accessibility to discharge data.

Furthermore, the significant disparity and heterogeneity in hydrological properties between monitored and unmonitored areas limits the possibility to generalize results based on monitoring data. Systematic differences in the characteristics of monitored areas between continents may also imply that conclusions drawn regarding continent-to-continent differences in hydrologic behavior in fact depend on the characteristics of accessible data that may not be representative of the continent as a whole. The reliable identification and understanding of carbon mobilization processes in high-latitude tundra and carbon-rich soils requires a finer grained mask of stations, extended monitoring in permafrost ground, and more ready access to data. Monitoring would need to be extended to cover anthropogenic pressures in the European and Western Siberian part of the pan-Arctic, where economic activity is expected to increase (Andreeva, 1998), and extended in North America and Asia to better represent the permafrost and vegetation types present on the northern rims of these continents. Also, diverging spatial patterns in future modeled and recently observed temperatures make it difficult to determine whether the basins with the greatest decline in discharge monitoring density are really the ones that will experience the greatest future temperature change.

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Improved use of water resources in northern Syria

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Keywords: participatory research, supplemental irrigation, groundwater, climate analysis

ABSTRACT

In northern Syria, average annual precipitation (250-400 mm/yr) is generally not sufficient to provide the full water requirements of wheat, the most common winter crop. The development of tube wells, and subsidized diesel fuel for running a pump have provided farmers with an affordable source of irrigation water to increase and stabilize their yields. However, groundwater recharge rates in this area hardly exceed 5%, and uncontrolled irrigation has resulted in a widespread decrease of groundwater tables and the drying up of wells. This paper evaluates the long-term trends in precipitation and reference evapotranspiration (ET_o) and their effects on the winter cropping season in northern Syria. Secondly, it evaluates how knowledge developed in controlled research trials can be used by farming communities to improve the productivity of their resources, based on ongoing work in the community of Al-Ajaz. Non-parametric trend analysis revealed that precipitation and evapotranspiration in Tel Hadya (1979-2007) in northern Syria did not show any evidence of trends. In the poorly distributed rainfall season of 2006/07, average yields in bread-wheat variety trials under different levels of farmer-managed irrigation ranged between 2.23 and 6.49 ton/ha, with estimated water productivities ranging between 0.7 and 1.3 kg/m^3. The results of the work indicated that improvements in farmer water management in combination with crop varieties that are most suited for the environment could reduce groundwater use while providing good yields for all farmers.

INTRODUCTION

The population in northern Syria has greatly expanded during the last three decades. With an average annual rainfall between 250 and 400 mm over a large part of the area, access to groundwater for irrigation has had a positive impact on the productivity and incomes of the communities in the region. However, the groundwater pumped today has accumulated over thousands of years. Current day recharge mainly occurs during exceptional sequences of large rainfall events and in the more hilly areas with shallow soils. Luijendijk and Bruggeman (2007) estimated recharge in this area to range between 3 and 8% of the annual rainfall.

The declining groundwater levels are affecting the livelihoods of the farming communities. In the community of Al-Ajaz, a young community member, who has developed his skills as a facilitator through his job at ICARDA, has mobilized the community to improve their resource use efficiency and to build their capacity for growing high value crops. The goal of the here presented research was to test how knowledge on supplemental irrigation and improved bread-wheat varieties developed under controlled research conditions (e.g., Oweis et al, 1998) can be used, adapted and transferred by farming communities, with Al-Ajaz as our pilot site.

METHODS

The community of Al-Ajaz is located in northern Syria, 40 km southwest of Aleppo. The community has 50-60 households. Land use is highly fragmented, with the majority of the households owning around 2 ha of farm land. The region is covered by Mediterranean red clay soils (Calcixerollic Xerochrept) but soil properties vary between and within fields due to variable soil depths, stone contents and manure applications. Groundwater is drawn from the productive upper aquifer formed by the Helvetian limestone formation (Middle Miocene), which is approximately 200 m thick in this area (Technoexport, 1966). Most of the farmers in the community own an irrigation well. According to the farmers, groundwater levels have dropped substantially during the last two decades.

Reference evapotranspiration (ETo) was computed for the daily climate data (1979-2007) of the ICARDA research station at Tel Hadya, 10 km north of Ajaz, following the methods of Allen et al. (1998). The probability distribution of the annual precipitation and ETo data was assessed with the help of Cooke et al (1993). A series of non-parametric techniques (including seasonal Kendall test, Mann-Kendall tests for individual months, Sen slopes) as described by Gilbert (1987) were used to analyze for the occurrence of long-term trends in the precipitation and ET_o data. The performance of non-parametric methods, in terms of power and efficiency, has been found to be similar or better than that of parametric methods in case of slight deviations of normality (Hirsch et al, 1991).

Farmer meetings were held in May 2006, to assess the community's practices and problems in supplemental irrigation. This activity also served as a practical exercise for a group of trainees from the National Research and Extension Systems of the West Asia and North Africa region and included a separate women's meeting. In early November 2007, community meetings were organized to identify the interest of the farmers in testing different technologies and to plan the research activities.

Bread wheat trials were established in eight farmers fields in late November. After the discussions with the farmers, ten varieties were selected by the breeder, with a different set of drought tolerant varieties for two of the farmers who did not have an irrigation well (Field 4 and 8). In two of the irrigated fields (Field 5 and 7) two additional varieties were grown. The trials were planted by the agronomy group in late November. Each variety was grown in a 4.5-m by 10-m plots in randomized complete blocks with two replicates in each field. Volumetric samples for initial soil moisture of the root zone were taken at two locations in each field.

Estimates of the soil moisture conditions of each farmer's field were made based on the initial soil moisture content, crop development; rainfall measured by a tipping bucket rain gauge established in the community; and ET_o from the Tel Hadya station, using an adjusted version of the spreadsheet-based model of Allen et al (1998), as presented by McCann et al (2007). The water balance computations were presented and discussed with the farmers on April 1, just before they started their spring irrigations. The farmers applied irrigation with one or more lines of sprinklers, moving their set of pipes throughout their fields. Farmers were visited regularly to check on the timing of their irrigations and irrigation rates were estimated by measuring volumetric soil moisture contents and wetting depths before and after some of the irrigations.

A farmer field evaluation was held on 23 May 2007, approximately two weeks before harvesting. The wheat farmers from Ajaz were joined by a group of 12 visiting farmers and accompanying staff from the Ministry of Agriculture, from Mosul, Iraq. Two female farmers also participated in the evaluation. Each farmer was given a set of forms and asked to score each variety from 1 (excellent) to 5 (poor) and to note the reasons with the score. Field 2, 3, 4, 5, and 8 were evaluated by the group. Final ranks were computed from 13 sets of score sheets, with most of the Iraqi group preferring to keep their forms. The top 3 ranking varieties of each field were compared with the yield results of that field.

The fields were harvested 4-10 June. For each plot, yield results of the middle 1.4-m wide row over the full 10-m length of the plot were measured directly on-site and all yields and data were provided to the farmers. Soil moisture was again measured in each field, using gravimetric samples. Analysis of variance (ANOVA) was conducted to test the effect of varieties and farmer irrigation management on grain yields. To assist with the selection of the best performing varieties for this environment, the top 2 yielding varieties of the eight irrigated fields were compared.

RESULTS

Climate Analysis

The average monthly precipitation and ET_o during the main November to May cropping season and the monthly extremes for the 28-year period are presented in Figure 1. The 2006/07 season's rain was below average in all months except May. The rainfall and ET_o in December 2006 set new extremes for the 28-year record (Fig. 1). The December-May rainfall in Al-Ajaz (193 mm) was lower than that of Tel Hadya (230 mm).

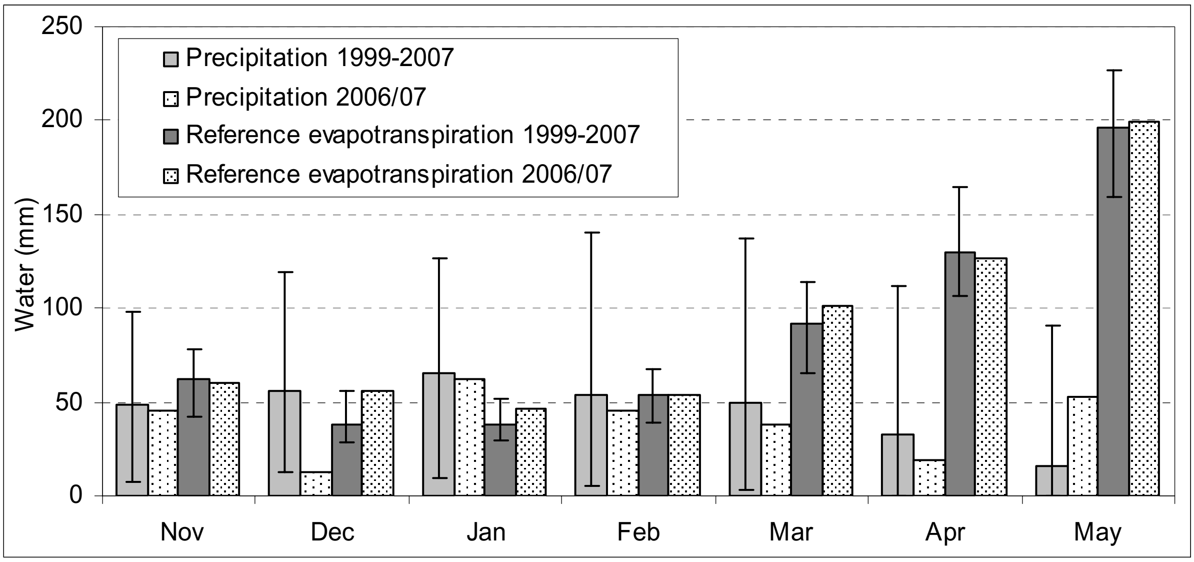

Figure 1. Average monthly precipitation and reference evapotranspiration measured at Tel Hadya, for the 1999-2007 period and the monthly data for the 2006/07 crop season, with the error bars indicating the minimum and maximum of the 28-year period

Both the annual precipitation and ET_o totals could be considered normally distributed, according to the chi-square test. However, some of the monthly rainfall data were clearly better fitted by log-normal than normal distributions. Therefore, non-parametric procedures were used for the time trend analysis. The chi-square test indicated that there was no of heterogeneity of trends between months; and no evidence of trends was detected in the annual and monthly precipitation and ET_o data of Tel Hadya for the 1979-2007 period. The smallest p-values for the individual Mann-Kendall statistics of the monthly precipitation data were found in May ($p=0.173$) and in November ($p=0.235$). The May precipitation showed a slight decrease with time (Sen slope -0.25), whereas the November precipitation seemed to be on the increase (Sen slope 0.74).

Participatory testing of bread-wheat varieties under supplemental irrigation

The farmers identified the high costs, and the scheduling of irrigations as main problems for the supplemental irrigation of winter crops. A reduction in the already subsidized price of diesel fuel for running the pump (currently about $0.15 per litre), as well as technical support were given as potential solutions. Interestingly, the sustainability of the groundwater was not brought up at all.

Farmers are not just interested in a single crop or technology, and agronomists, breeders, and water scientists joined the meetings with the farmers before the start of the winter crop season. Clearly, research at the community level requires an integrated approach. As a result of the meetings participatory wheat and barley trials were established in the community, and improved lentil and chickpea varieties were also tested by selected farmers.

The farmers' main criteria for scheduling their irrigations were their general experience, the approximate time since the last rain and any stress symptoms displayed by the crop. Weather forecasts and cloudy skies were not considered. Some of the farmers showed a keen interest in the soil moisture sampling. The farmers were happy to listen to our scheduling advice, especially if this agreed with their own perceptions. However, the somewhat better-off farmers tend to prefer the chance of applying too much than to apply too little. These farmers also perceived that they had a very good water source.

One of the most challenging aspects of community-based research is to estimate the amount of water applied by the different farmers. No meters are used by the farmers and irrigations applications are quantified in hours. The number of sprinklers per area, nozzle size, and water pressure varied both within and between fields and irrigations. Although the farmers were happy to tell when and how many hours they irrigated, their memory is not always accurate. The computed soil moisture balance for Field 1, which received the highest number of irrigations of the eight fields, is presented in Figure 2. It can be seen that the scheduling decisions of this farmer were fairly sound.

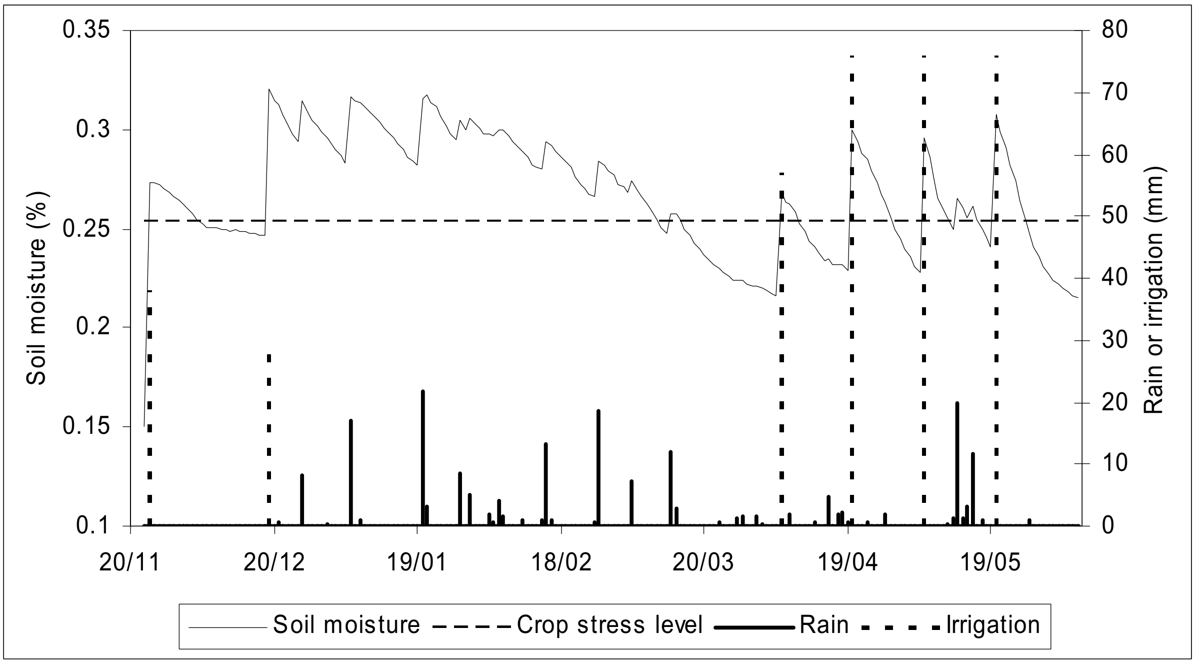

Figure 2. Computed soil moisture in the root zone of Field 1 during the 2006/07 crop season

The estimated total water applied and used by the crop, including rainfall and change in soil moisture between planting and harvesting are presented for all eight fields together with the average yields and water productivities in Table 1. The range between the poorest and best performing variety (average of two replicates) was lowest in the field with high irrigation levels and highest in Field 5, which had a medium water use level. However, the effect of the different varieties on yield was more significant (low p-values) in the fields with the highest water use than in the fields with the lower irrigation applications. This is likely due to the high variability between replicates in the fields that received less irrigation, which seemed to have a low uniformity. Some overlaps occurred between the minimum yield at a certain water level and the maximum yield at the next level down. This indicates that theoretically the effect of more sustainable irrigation rates could be off-set by the use of better varieties. As expected, the two-analysis ANOVA for the ten similar varieties in the six irrigated fields (Field 1-3, 5-7) showed a highly significant effect of the farmers management on the yields ($p<0.001$) and also a significant but smaller effect of the different varieties ($p=0.018$), and no interaction effect.

Table 1. Average, minimum and maximum yields of the bread-wheat varieties in each field, p-value for 1-way ANOVA of varieties in each field, estimated water use and average water productivity, sorted in order of decreasing water use

Field	Average yield, ton/ha	Minimumyield, ton/ha	Maximumyield, ton/ha	p-value	Irrigations, #	Estimated water use, mm	Av.water productivity, kg/m^3

Field 1	6.09	5.57	6.94	0.029	6	549	1.1
Field 2	6.49	6.16	7.04	0.034	4	486	1.3
Field 7	5.35	4.38	5.98	0.044	4	450	1.2
Field 5	4.78	3.40	5.75	0.182	3	396	1.2
Field 6	4.88	4.28	5.46	0.605	3	388	1.3
Field 4	2.23	1.66	2.75	0.055	0	336	0.7
Field 3	3.30	2.50	4.09	0.395	4	293	1.1
Field 8	3.12	2.26	3.80	0.158	1	268	1.2

The data also indicated that even in a dry year, 3 irrigations (around 200 mm total) could bring yields up to 5 ton/ha. Field 4 had very high initial soil moisture, after the irrigation of tomatoes in summer, but ran out of water towards mid April. Field 3 had poor soils and low initial soil moisture contents and although the farmer irrigated four times, his applications were not sufficient (approximately 30 mm). Field 8, which was originally planned to remain rainfed, but received one irrigation in mid April, supplied by the brother of the female owner, when rains remained scarce. The performance of the top 2 yielding varieties of the six irrigated fields over the different water use levels is visualized in Figure 3. Variety 10 (Almaz-21) was the highest yielding variety in the three wettest fields, whereas Variety 4 (Shuha-7-cross) performed best in the drier fields (Field 3,5).

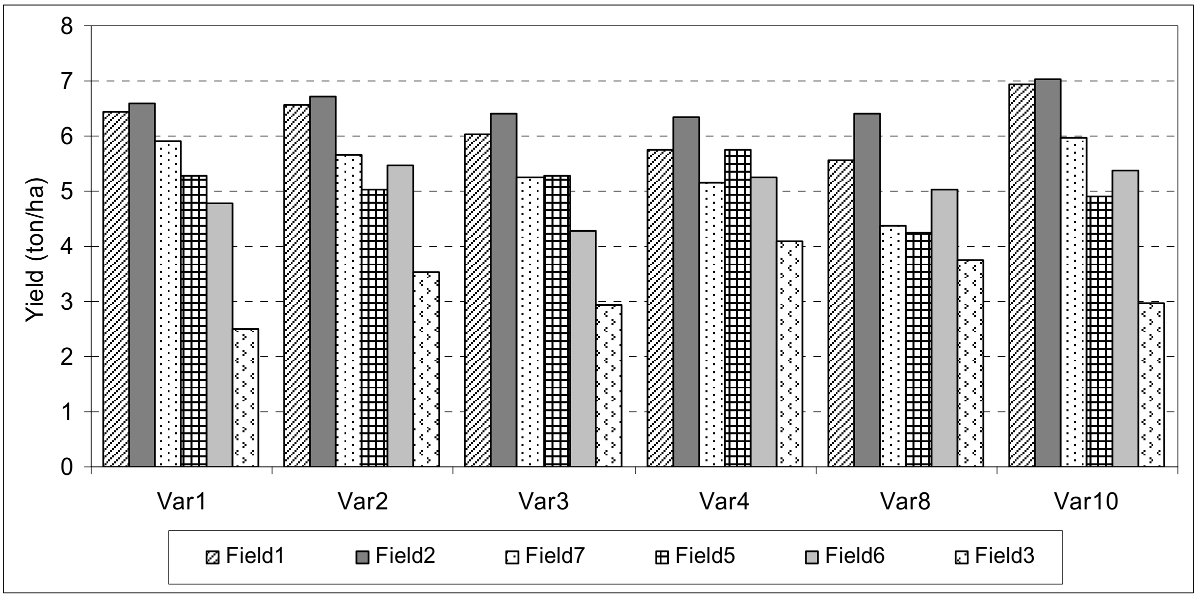

Figure 3. Yields of the top-2 varieties from each field, with fields in decreasing order of water use

During the discussions on the farmers' field day on May 23, Field 2, which eventually obtained the highest yields, and Field 8, which had drought resistant varieties but had received one irrigation in April, were best appreciated. Farmers scored the different varieties mainly on the size of the head. They also tended to favour the taller varieties. But the farmers also indicated that the final yield data would be the best indicator. The variety that eventually obtained the highest yields in Field 3 and 5, was ranked first in the farmers' evaluation in Field 3 and third in Field 5. The highest yielding variety in Field 4 and Field 8 (both Cham6-cross) was ranked number 1 and 3, respectively. No other overlaps were found between the top 3 yielding and the top 3 farmers' scored varieties.

DISCUSSION AND CONCLUSIONS

No evidence of climate change was found in the 28-year record (1979-2007) of Tel Hadya station in northern Syria. But the fairly high short term variabilities have important impact on the rainfed crop production in this region. Most farmers protect themselves against the vagaries of the climate through application of supplemental irrigation to the rainfed crop in times of drought. But the unsustainable use of groundwater is putting the future use of this resource at stake. Thus, in this region, improved groundwater management is perhaps a more acute concern than climate change.

Farmers in the community of Ajaz, generally did quite well in timing their supplemental irrigation applications. However, one of the key problems is that they do not really know how much water they apply. This resulted in ineffective irrigations and potential losses. Initial soil moisture contents were highly variable for the eight test fields, as a result of previous crops and irrigations. Considering the highly variable initial conditions in the different fields, it is difficult to provide a farming community with generic irrigation scheduling advice based on real-time climate data.

For the coming season, the number of varieties per field will be reduced to the top 2 or 3 performing varieties for each field. The economics of the water use will be discussed with the farmers. The farmers' capacity in irrigation scheduling will be improved with the help of field rain gauges for measuring irrigation applications and soil moisture wands for assessing the moist soil depth. Irrigation advice will be provided and followed with the help of daily climate data and regular neutron probe measurements in a limited number of fields. Attention will be given to both the poorer and the somewhat better-off farmers. The aim of working with the first will be to improve irrigations and thereby their productivity and incomes, whereas working with the latter aims at reducing the stress on the aquifer.

ACKNOWLEDGEMENTS

Participatory community-based research requires an integrated approach, and we would like to thank ICARDA scientists Anthofer, Turkelboom, Cecarelli, Grando, Sarker, Malhotra, Farahani, and Martini; and research support staff Ali Haj Dibo and Pierre Hayek, among others, who contributed to the cooperation with the community. The irrigation aspects of this work have also benefited from research linkage funds provided by the United States Agency for International Development.

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Adaptation to the impacts of climate change in the water sector

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The general challenge of climate change is to consider how it will affect different ecosystems and human activities, what kind of responses may ensue, and how these responses may change established relationships between climate and place. Any planned or reactive form of adaptation will affect this relationship directly, and any greenhouse gas mitigation that occurs (e.g. carbon sequestration, biofuels) may create other feedbacks and alter the pattern of climate change impacts over space and time. However, development paths themselves may also change the relationship between climate and place. Population growth, land use modifications, technological changes, shifts in international trade, and evolution (or revolution) in governance can alter how climate-sensitive resources are managed, what techniques are used for resource exploitation, and where communities large and small can grow.

There are many uncertainties associated with impacts and adaptation studies. Uncertainty can extend from the initial projections of future emissions, which can lead to various carbon cycle responses, different global climate sensitivities, regional climate change scenarios, and then the range of possible impacts, which would themselves be influenced by unique regional circumstances of vulnerability and adaptive capacity (IPCC, 2001, 2007). It's easy to feel overwhelmed by cascading uncertainties, and to question why anyone would bother to try doing an impacts and adaptation assessment. But nevertheless, there is a growing body of literature on climate change impacts and adaptation, because investigators are beginning to draw some boundaries around the problem, hopefully within manageable limits. The impacts research community rarely becomes directly engaged in considering the uncertainty aspects of the climate models themselves. The climate science community has its own scientific debate on such issues. As a consumer of climate information, the impacts community is trying to use whatever tools it has to translate climate change scenarios into a different form of knowledge that is meaningful to resource managers, communities, investors, governments, and various other interests. This requires explicit consideration of the nature of information flow between global climate science and local decision making.

When considering the specific challenges of defining climate change impacts on the water sector, and then assessing the effectiveness of adaptation options, there are both bio-physical and socio-economic elements that must be considered. The hydrologic cycle, including human and ecosystem requirements for water, are sensitive to variations in climate, and are certain to be affected by climate change. Climate change is expected to alter patterns of runoff, evaporation, snowmelt, soil moisture, lake and river levels, and water temperature (including the seasonal formation and melting of ice). These effects will be unique to each region and watershed (IPCC, 2001, 2007).

There are several factors that are increasingly affecting both the quality and availability of water for water users. Year-to-year climatic variability affects the atmospheric water availability, which in turn affects the surface water availability, groundwater availability and net water availability for agriculture and domestic users. An increasing dependence on irrigation or domestic water systems can occur at the save time that other water users (e.g., municipal, industrial, ecological) also demand and use more water. As a result, competition for water supply, both for withdrawal uses and for in-stream flow needs, has given rise to concerns over water scarcity and potential conflicts among all users, particularly during times of drought.

Drought is a natural recurring event, but future drought occurrences may be affected by climate change, which is expected to cause significant decreases in streamflow, groundwater and lake levels in many regions. Runoff from snowpacks and glaciers is also expected to decline in most mid-latitude and tropical regions. The frequency and severity of climate extremes, such as future drought events, are expected to be altered under a changing climate. Thus, not only is climate change likely to increase competition for a declining water supply, it may also lead to a greater reliance on managed water systems to reduce vulnerability to year-to-year climatic variations. This will be both a technological and a governance challenge (Wilhite, 2005).

A case study from the Okanagan region, a semi-arid watershed in British Columbia, Canada, is presented as an example of a shared learning experience, in which researchers and local practitioners combined knowledge, data, and perspectives, to produce a decision support model for assessing the effectiveness of adaptation options within scenarios of climate change and regional population growth (Cohen and Neale, 2006; Cohen et al., 2006; Langsdale, 2007). The model uses existing local climate impact scenarios of water supply and demand, and local system information, and offers model users an opportunity to explore various options, including reducing water demand, altering water storage, and changing the mix of crops. Some options are represented as yes/no, while others permit quantitative alterations within specified limits. This model is not intended to be an operational tool, but it is hoped that it can facilitate dialogue on proactive adaptation, and ultimately, facilitate linkage of climate change, water resources, and long term regional development.

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Climatic variation, glacier recession and runoff from Alpine basins

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Keywords: climatic variation, meltwater discharge, glacier recession, Alpine basin

ABSTRACT

Records of discharge of rivers draining basins with between 0 and ~70% ice cover, in the upper Aare and Rhône catchments, Switzerland, for the period 1894 through 2006 have been examined together with climatic data from 1865 through 2006, with a view to assessing climatic and glacial influences on temporal patterns of runoff through two cycles of warming coupled with sustained reduction of glacier mass. Runoff in the highly-glacierised basins mimicked mean May-September air temperature through cycles of warming in the 1940s-1950s and 1990s-2000s, whereas flow from (near) ice-free basins reflected precipitation, increasing to the 1960s and 1970s and declining to the warmer 2000s. Levels of runoff before and during the first warming period were not exceeded during the second, as a result of precipitation decreasing and glacierised areas diminishing. Response of runoff to exceptionally-warm summers was influenced by both scale and vertical extent of glacier cover.

INTRODUCTION

During a period of sustained climatic warming, runoff from glaciers might be expected to increase as a result of enhanced melting of snow and ice. Higher annual total discharges resulting from warmer summers can however not continue indefinitely as the amount of water stored as ice is depleted. As glacier mass loss translates into declining glacier-covered area, glacier runoff will be reduced and ultimately cease as glaciers disappear altogether (e.g. Jansson et al., 2003). Through time, runoff in all Alpine basins will be influenced by changes in the water balance, i.e. precipitation – evapotranspiration, river flow decreasing with reducing precipitation and vice versa. Changes in glacier mass are also influenced by trends in precipitation, since annual net mass balance is influenced by the relative quantities of snow accumulation with respect to summer energy availability for melting. Temporal variations of mass balance can result from changes in energy availability with constant precipitation, changes in precipitation but constant energy availability, or changes in both. The less the percentage basin glacierisation, the more year-to-year variations in runoff are influenced by those of precipitation (Collins, 1989).

Underlying patterns of runoff from Alpine basins have fluctuated considerably in response to two cycles of warming since the mid-nineteenth century (Collins, 2006). Those climatic fluctuations led also to cumulative loss of mass and reduction in glacier size from maximum dimensions attained during the Little Ice Age (e.g. Maisch et al., 1999). Throughout this period, in glacierised basins, glacier recession must have added an unsustainable component of flow to runoff, which is otherwise related to contemporary levels of precipitation. The aim of this paper is to examine changes in runoff from five Alpine basins, with ice cover of between 0 and ~70% of catchment area, from the end of the nineteenth (where records are available), through the twentieth, and into the twenty-first century. These data permit assessment of runoff through two warming cycles during which glacier recession was generally sustained (Collins, in press). Significant questions include whether rates of increase of energy input were sufficient to offset declining ice surface area exposed to melt, whether the area of ice lost at margins and terminus has been offset by generally increasing melt at higher elevation, and how the glacial contribution has varied as a proportion of total runoff. Changes in amounts of runoff are described and flows in years in which, as a result of warm summers, runoff from the glacierised basins was prominent with respect to surrounding years are assessed.

CHARACTERISTICS OF THE BASINS AND MEASUREMENTS

Locations of the study basins in the upper Aare and Rhône basins in Switzerland are shown in Figure 1. Characteristics of the study basins are given in Table 1 and elevation ranges of the glacierised areas within the basins are shown in Figure 2. Percentage glacierisation of basin area was taken from the contemporary annual *Hydrologisches Jahrbuch der Schweiz* (e.g. Bundesamt für Wasser und Geologie, 2006). The Allenbach basin is ice-free. Near ice-free Grande Eau basin, into which since 1942 some water has been transferred from the Arnensee, contains Glacier de Pierredar (1.25 km^2 in 1973). Total glacier-covered areas of about 32 and 22 km^2 in the Lonza and Rhône basins declined by about 10% and 7.5% respectively between 1977 and 2002. Following dam construction, from 1965 the Massa was gauged at Blatten-bei-Naters, upstream of the former station at Massaboden, reducing basin area by 3.47%. Percentage glacierisation of the Massa basin, recalculated to take into account catchment area change (Table 1), reflects loss of total ice-covered area of about 8 km^2 (6%) from 136.6 km^2 between 1934-2002, of which about three-quarters had disappeared by 1957. Runoff in the Massa is unlikely to have decreased by as much as the reduction in (ice-free) basin area. Annual runoff (Q_{1-12}) from a basin is the total for the calendar year. Mean May through September air temperature (T_{5-9}) recorded at Sion (Couvent des Capucins) between 1865 and 1977 indicates energy availability for melting. Subsequent values of T_{5-9} for Sion are estimated from observations at Grächen. Total annual precipitation between November in one year and October in the next (P_{11-10}), measured at Zermatt, reflects build up of winter snow pack and summer rainfall.

TEMPORAL VARIATIONS OF CLIMATIC VARIABLES AND RUNOFF

From a minimum in 1888, T_{5-9} increased to the late 1940s, with a maximum in 1947, before declining until the late 1970s. A second warming period from the 1980s to the early twenty-first century includes the warmest summer (2003) in the 1865-2006 record, on an underlying gently rising linear trend from the 1880s (Figure 3). P_{11-10} varied roughly inversely with T_{5-9}, being relatively low from

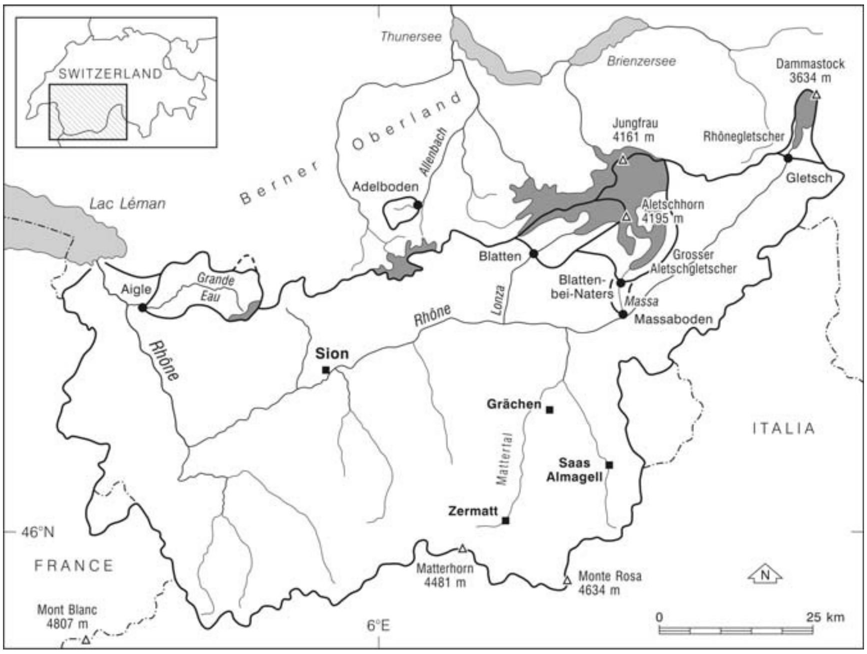

Figure 1. Locations of study basins in the upper Rhône and Aare catchments, Switzerland. Gauging and meteorological stations from which records have been used are indicated. Glacierised areas within and around the study basins are shaded.

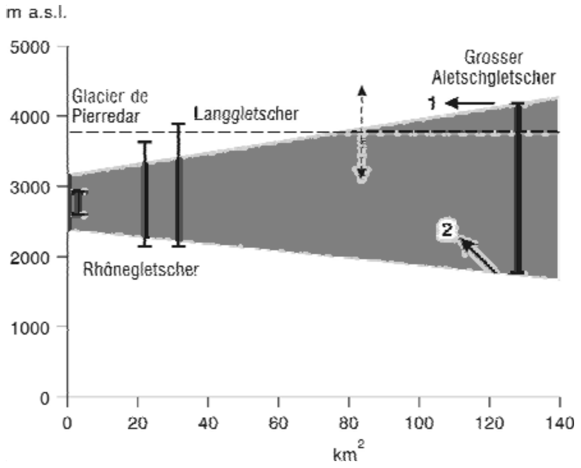

Figure 2. Elevations of upper and lower limits of glacierised areas (solid lines) plotted against basin glacierised area. The pecked lines indicate a range of possible elevations of the transient snow line in summer. As a glacier declines in area, the elevation of the upper margin is maintained (arrow 1), whereas the terminus retreats upslope (arrow 2).

Table 1. Characteristics of the study basins

River/Gauging station	Principal glacier	Basin area km²	Basin glacierisation year	%
Allenbach/Adelboden		28.8		0.0
Grande Eau/Aigle(+Arnensee)	Glacier de Pierredar	132.0 (139.1)	1977	1.9 (1.8)
			2002	1.8 (1.7)
Lonza/Blatten	Langgletscher	77.8	1977	40.6
			2002	36.5
Rhône/Gletsch	Rhônegletscher	38.9	1977	56.4
			2002	52.2
Massa/Massaboden	Grosser Aletschgletscher	202.0	1927	68.3
			1934	67.6
			1957	64.1
Massa/Blatten-bei-Naters		195.0	1957	66.4
			1977	66.6
			2002	65.9

the late 1920s to the 1950s. 1942/43 was the driest year in the twentieth century. Precipitation then increased to the early 1980s, accompanying cooler summers, with 1979/80 the wettest year since 1913/14. Precipitation was below average for much of the warming cycle from the 1980s, associated with sustained high pressure anomalies (Beniston & Jungo, 2002). 2003/04 was the driest year since 1892/93.

Runoff (Q_{1-12}) in the Massa, which drains the most highly-glacierised basin, mimicked the cyclical pattern of variation in T_{5-9} at Sion (Figure 3). Flows in the warmer 1990s-2000s (T_{5-9} 19.07°C, Q_{1-12} 482.84 $\times 10^6 m^3$ for 1997-2006) failed to exceed those of the 1940s-1950s (T_{5-9} 18.26°C, Q_{1-12} 505.96 $\times 10^6 m^3$ for 1943-1952), glacierisation having decreased and annual average precipitation reduced to 581 from 657 mm in respective periods. 1928, 1947 and 2003 stand out as peak runoff years ranked third, first and second largest, with T_{5-9} 17.80, 19.77 and 20.85°C respectively. 1928 appears to have been anomalous, overall unexceptional energy input masking a warm spring, which followed substantial winter precipitation. Runoff from both Massa and Rhône basins increased considerably from the cooler wetter 1960s-1970s to the warmer drier 1980s -2000s, quinquennial average runoff in the Massa increasing by almost 50% between 1974-1978 and 2001-2005. However, flows in the Rhône during the 1980s-2000s warming cycle failed to reach the discharge maximum attained in 1900, and the 1928 runoff level was exceeded in only 1994 and 1999. Again, T_{5-9} was unexceptional

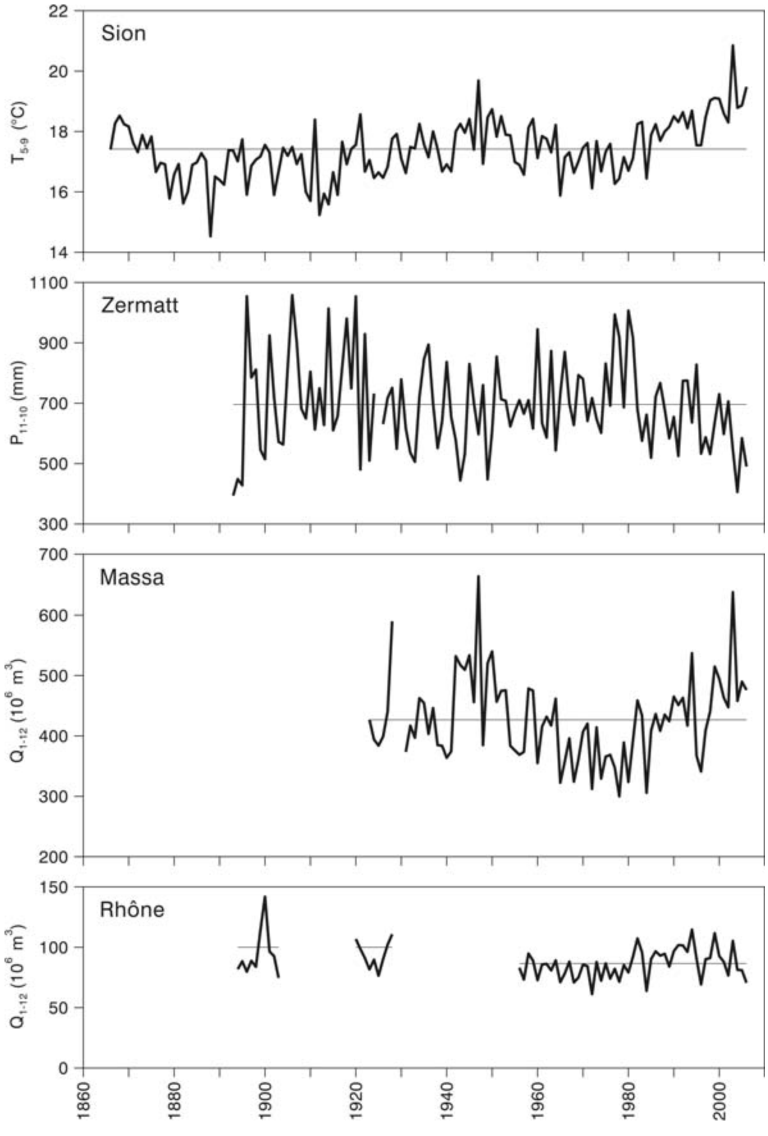

Figure 3. Year-to-year variations of mean summer air temperature ($T_{5\text{-}9}$) at Sion, annual total precipitation between November and October ($P_{11\text{-}10}$) at Zermatt, and annual total discharge of the Massa and Rhône ($Q_{1\text{-}12}$) in the period 1865–2006. From 1978 through 2006, $T_{5\text{-}9}$ at Sion was estimated from the records at Grächen. For the Massa, discharge measurements were interrupted in 1929 and 1930, and the station relocated upstream from 1965. For the Rhône, two short discrete periods of measurement preceded the continuous record. Series means are indicated by horizontal lines.

in 1900. Although the prominent runoff years of 1982, 1994, 1999 and 2003 also stand out in the Rhône record, discharge in the warmest was lower than in the other three years.

Runoff in the (near) ice-free Allenbach and Grande Eau generally reflected the temporal variation of precipitation, rising to maxima in the late 1970s and late 1960s respectively (Figure 4). Year-to-year fluctuations of runoff were broadly parallel, with some prominent years in the 1990s. Flow in the Allenbach and Grande Eau declined by 11 and 16% respectively from 1977-1986 to 1997-2006. Relatively high flows in 1995, 1999 and 2001 suggest that the tendency to lower levels of precipitation indicated by the record from Zermatt was not experienced throughout the region. Temporal variation of discharge in the Lonza (~38% glacierised) was to an extent intermediate between that in the Allenbach (0%) and Rhône (~54%). Decline in runoff from the Lonza was not so marked between 1987-1996 and 1997-2006 as that from the other two basins.

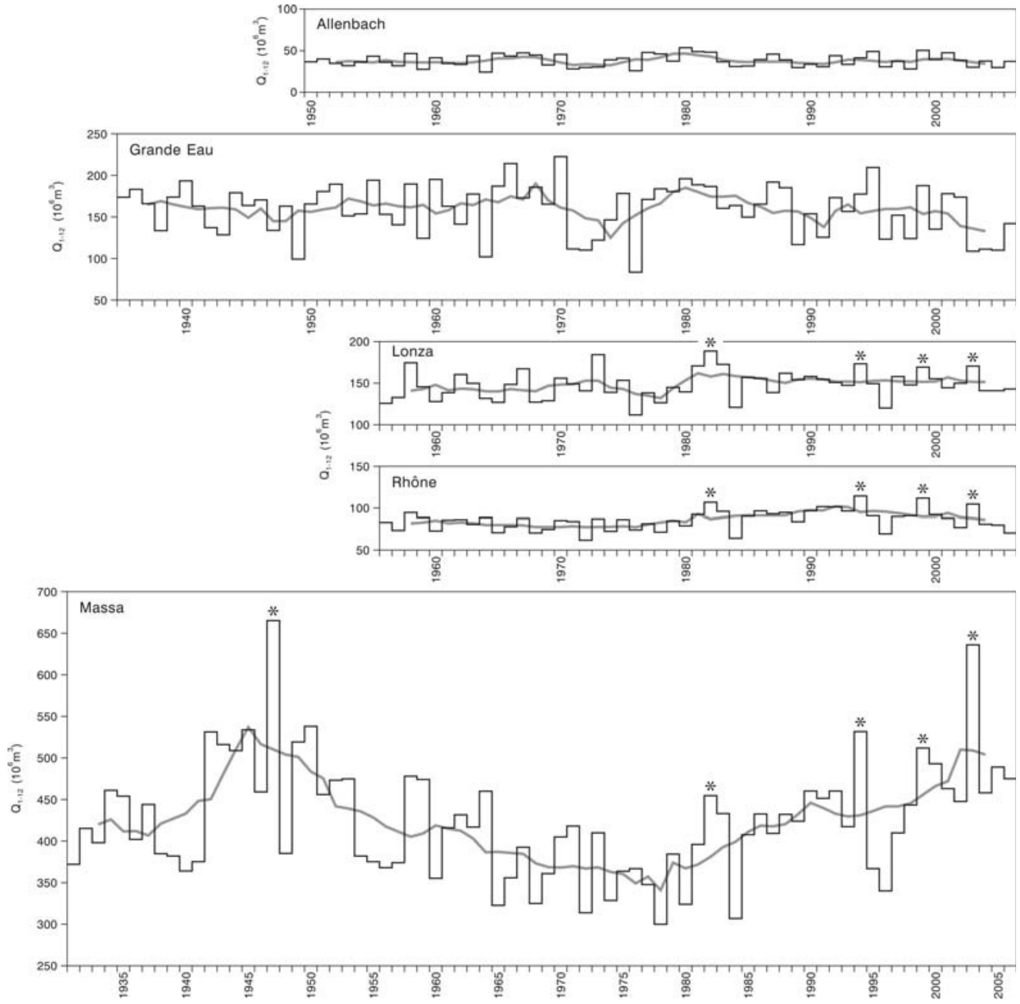

Figure 4. Year-to-year variations and five-year moving averages of annual total discharge (between January and December (Q_{1-12})) of the Allenbach, Grande Eau, Lonza, Rhône and Massa in the period 1930–2006. For the glacierised basins, years with warm summers in which total discharge was prominent with respect to levels of flow in surrounding years are indicated by *.

Table 2. Ranking of mean summer air temperature and runoff from the glacierised basins for years with warm summers in which runoff was enhanced with respect to surrounding years

Rank order	T_{5-9}		Q_{1-12}	
	Sion	Lonza	Rhône	Massa
1	2003	1982	1994	2003
2	1999	1994	1999	1994
3	1994	2003	1982	1999
4	1982	1999	2003	1982

DISCUSSION AND CONCLUSION

In the glacierised basins, during the second warming cycle, the same four years (1982, 1994, 1999 and 2003) are prominent in all three runoff records, having total annual discharges higher than in the years immediately before and after. Surprisingly, the exceptionally warm summer of 2003 produced the highest runoff of the four years in only the most highly-glacierised basin, Massa (Figure 4, Table 2). From the 54%-glacierised Rhône basin, runoff was lower in 2003 than in the other four years, having reached highest levels in the early 1990s before declining. In the Lonza, runoff in 2003 exceeded that in 1999, relatively high precipitation in the latter year notwithstanding. Meltwater production is a function of the ice area over which heat can be exchanged, so that absolute glacier dimensions influence runoff. As indicated in Figure 2, Langgletscher is larger than Rhônegletscher. Figure 2 also shows elevation ranges of the glaciers in the study basins. Assuming, in a warm ablation season, the transient snow line rises to about 3750 m a.s.l., as indicated by the pecked line, winter snow accumulation will be removed from all the surface area of Rhônegletscher. At Langgletscher, however, which extends upwards a further 150 m, upper areas of the glacier will remain snow-covered, and similarly for Grosser Aletschgletscher. In an exceptionally warm summer such as 2003, rising of the transient snowline to yet higher elevation leaves the area of firn and ice exposed at Rhônegletscher unchanged, but the exposed areas of Langgletscher and Aletschgletscher are extended according to glacier hypsometry, and glacier contributions to runoff proportionally enhanced.

The pattern of variation of runoff from Alpine basins from the late nineteenth through early twenty-first centuries has been influenced by both scale and vertical extent of glacier cover. In (near) ice-free basins, runoff reflected precipitation fluctuations, increasing to the 1960s and 1970s and declining to the warmer 2000s. The greater the glacier cover, the more runoff from glacierised basins was influenced by energy inputs through the cycles of warming in the 1940s-1950s and 1990s-2000s. River flows before and during the first warming period were not exceeded during the second, as a result of both decreasing precipitation and diminishing glacierised areas. Even as temperatures reduced from the 1950s to the 1970s, precipitation generally seems to have been insufficient to prevent loss of glacier mass. Only in more highly-glacierised basins has destocking of ice been enough partly to offset otherwise declining flows during the second warming cycle. If glaciers continue to recede with continued warming and downward trend in precipitation, the amount of the glacial contribution to runoff, the deglaciation dividend, available to augment runoff will reduce, and the discharge of Alpine rivers will tend to levels reflecting only future precipitation amounts.

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Climate Change Impact on Rainwater Harvesting and Health in West Africa Urban Slums

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Keywords: rainwater harvesting, Africa, statistical downscaling, climate change, health, Markov model

ABSTRACT

Urban populations now exceed rural populations, creating unique challenges in providing basic necessities. West Africa is an acute example of the problems created by rapid urbanization, with high levels of urban poverty and low water and sanitation access rates. Rainwater harvesting is explored as a viable option in enhancing water supply to urban slum households. Simple stochastic weather generators are used to model rainfall in West Africa, which is then used to determine the reliability of providing a per capita supply of 20L/day. Results suggest domestic rainwater harvesting can have a significant positive impact on water supply enhancement in the region. Initial investigation into climate change impact indicates little change to domestic rainwater harvesting reliability for slum households.

INTRODUCTION

The world's urban population in 2005 was 3.15 billion and by 2030 will increase to 4.91 billion, nearly 60% of the global population (UNESA, 2006). The global shift of human population from rural to urban settings is most evident in sub-Saharan Africa, which is experiencing some of the planet's highest urbanization rates (UNESA, 2006). West African urban populations, already the highest in sub-Saharan Africa (Figure 1a), will continue to grow in the coming decades, even under a declining urban growth rate (Figure 1b). This soon-to-be majority of urban dwellers will increase existing social and environmental pressures associated with city expansion, resulting in growing numbers of urban slum dwellers, defined as those lacking any combination of adequate and safe drinking water, sanitation, durable housing, living space, and security of tenure (UN-HABITAT, 2003). If urban poverty rates remain the same, West Africa could see an additional 34 million urban dwellers living in these conditions, possibly negating Millennium Development Goal Target 11 efforts to eliminate slum conditions worldwide.

Rapid population growth in the developing world strains urban water supplies and infrastructure, as well as the local government's capability of providing new infrastructure to large, often illegal settlements (UN-HABITAT, 2003). Improved water and sanitation rates in sub-Saharan Africa are substantially less than most areas of the world, contributing to the many health problems associated with the area. Physical water scarcity and climate variability also contribute to water-related health issues, especially in the drier Sahelian regions of West Africa.

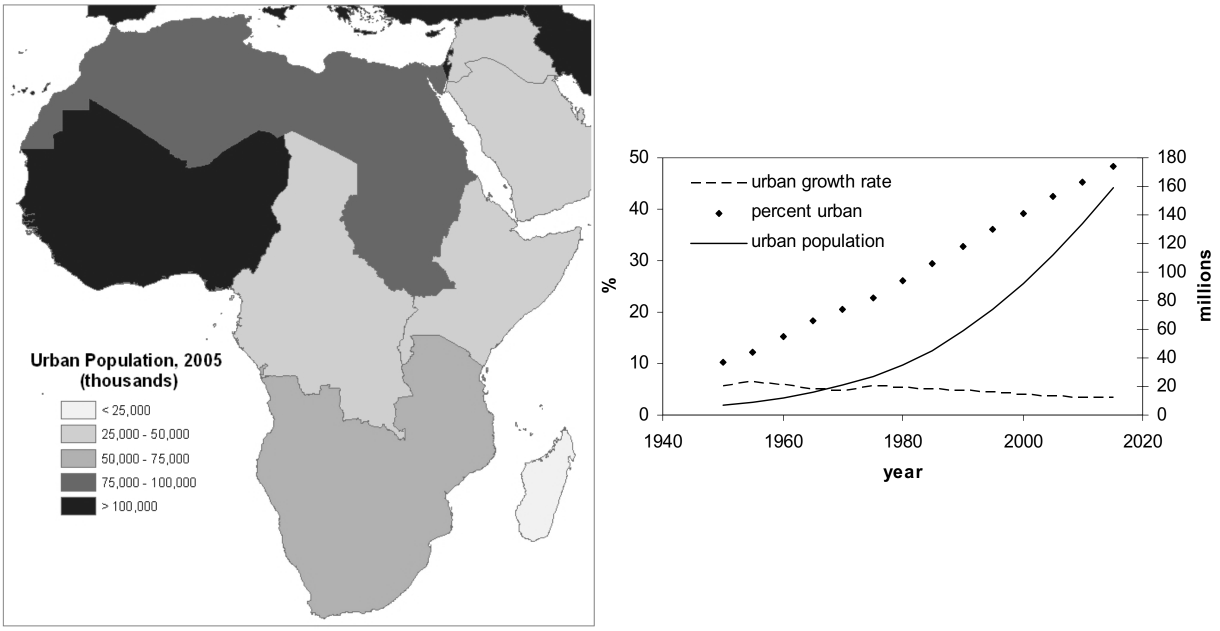

Figure 1: a) Urban Population Totals in Africa, b) West Africa Urban Population and Growth Rates (data from UNESA, 2006)

Domestic rainwater harvesting (DRWH) is an improved water technology recognized by the World Health Organization (WHO), and may be a partial solution to clean water shortages in West Africa urban slums. DRWH is an ancient technology still practiced formally (e.g. permanent collection/storage systems) and informally (e.g. pots under roof edges) in regions for supply enhancement and groundwater recharge and is readily appropriate for a variety of needs (Mihelcic et al., 2007). This technology has been experiencing increasing popularity in the past couple of decades in providing water where supplies are low due to water scarcity or poverty. These systems may be very compatible to the conditions found in impoverished urban communities, as they save time, money, and are less complex than other centralized treatment technologies (Thomas, 1998). This technology may also empower slum households in enhancing their own water supplies and subsequently their health, regardless of the availability and willingness of government infrastructure support and international economic aid (Cowden et al., 2006).

Rainfall data on a daily time scale is needed to assess the reliability of DRWH systems in slum households with little water storage capacity. Unfortunately, adequate rainfall records do not exist for many regions in developing countries. The development of rainfall models whose parameters may be spatially interpolated to ungauged basins is a practical option to facilitate hydrological and water supply models needing fine spatiotemporal input. Stochastic weather generators (SWG) are a common tool for this task and have been used extensively in developed countries. SWGs, however, have seen limited use in tropical and subtropical regions in developing countries, with very little application to DRWH (Sharma, 1996). This paper describes the application of a simple two-part stochastic rainfall generator that uses a 1st order Markov chain to represent rainfall occurrence and a two-parameter gamma distribution for rainfall amounts. This model will be used to assess the reliability of DRWH for gauge sites in West Africa, with future work including geostatistical interpolation of model parameters to assess DRWH at ungauged sites.

Initial investigation into the impacts of climate change on DRWH will also be presented in this paper. Current GCM multi-model averages for West Africa indicate both increases and decreases in precipitation, depending on the projected time period and time of year. There is also high uncertainty in this region as only half of the GCMs came to agreement on sign changes in this region under certain scenarios (Christensen et al., 2007). This uncertainty highlights the importance of comprehensive study of climate change impacts on rainfall in this region, as climate change is expected to increase risk in water-borne related health impacts in the developing world (McMichael et al., 2006). The stochastic rainfall model previously developed will be used to downscale global climate model (GCM) output to the local scale for such an assessment on climate change on DRWH in West Africa. GCM scales are too coarse for application to small-scale processes (e.g. DRWH), however, and require use of statistical downscaling methods or nesting of regional climate models (Wilby et al., 1998). Statistical downscaling methods are well suited for application in developing regions, which usually have inadequate data and resources for more costly regional climate studies.

METHODS

The National Climatic Data Center's Global Summary of Day data was used to estimate the parameters of the SWG (NCDC, 2006). Thirty-seven (37) gauges for the West African region were selected based on minimum record lengths of twenty years. Markov chain models, as applied to rainfall occurrence, assume current rainfall to be conditionally dependent upon rainfall occurrence of one or more previous days. This dependency in this study was limited to two states (*S*), wet or dry, and a time-lag of one day. This model order was preferred over a longer time-lag based on the Bayesian Information Criterion and sensitivity analysis on missing data. The transition probabilities, or probabilities of transitioning from one state to the other, were calculated for each month using the following:

$$\hat{P}_{ij,\ldots,kl} = \frac{a_{ij,\ldots,kl}}{a_{ij,\ldots,k}}$$

$$a_{ij,\ldots,kl} = \sum_{l=1}^{S} a_{ij,\ldots,kl}$$

where *a* is the frequency of each state transition (Gates and Tong, 1976). Random numbers were then compared against the transition probabilities to produce sequences of wet and dry days statistically similar to the observed time series.

Maximum likelihood estimates were used to fit 2-parameter gamma distributions to the observations of each gauge, and a random number generator was used to sample from the cumulative distribution to determine the rainfall amount on wet days of each simulation. Cowden et al. (2007) presents an initial investigation of the performance of the SWG model in this region.

The daily amount of rainwater harvested by a DRWH system was simply the product of the day's precipitation, an estimated per capita roof area of 4 m^2, and a runoff coefficient of 0.8. This quantity was then compared to a per capita water demand value of 20L/day, defined by WHO as a minimum threshold for adequate consumption and hygiene (Howard and Bartram, 2003). The reliability of the DRWH system was defined as the percentage of days in which this minimum demand was met.

The method outlined in Wilby et al. (1998) was used to assess the impact of climate change on DRWH reliability. This method uses a two-step process of extrapolating the climate change signal to the observed area average and then downscaling the adjusted values to the station level. The GCM used was the CGCM3.1/T63 model (Flato, 2005). The SRES A2 scenario is considered in this initial study (Meehl et al., 2007).

RESULTS

Figure 2 shows the simulated (model) reliability is slightly higher than observed due to the small overestimation of mean wet day amounts produced by the gamma amount model. The model's variability underestimates the observed variability, as is typical of SWG models (Wilks, 1999), but does adequately reproduces the mean DRWH reliabilities for each month.

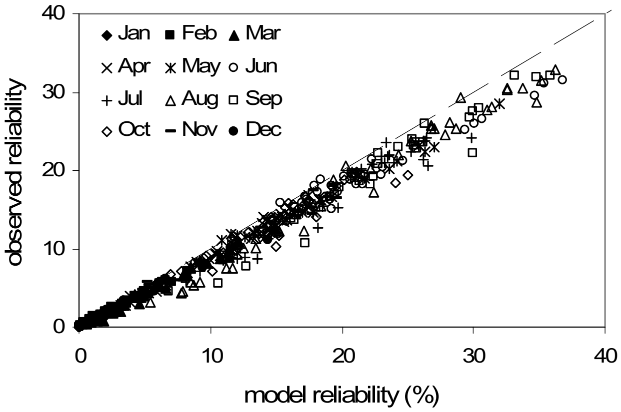

Figure 2: Domestic Rainwater Harvesting Reliability Metric for 1st Order Markov Model

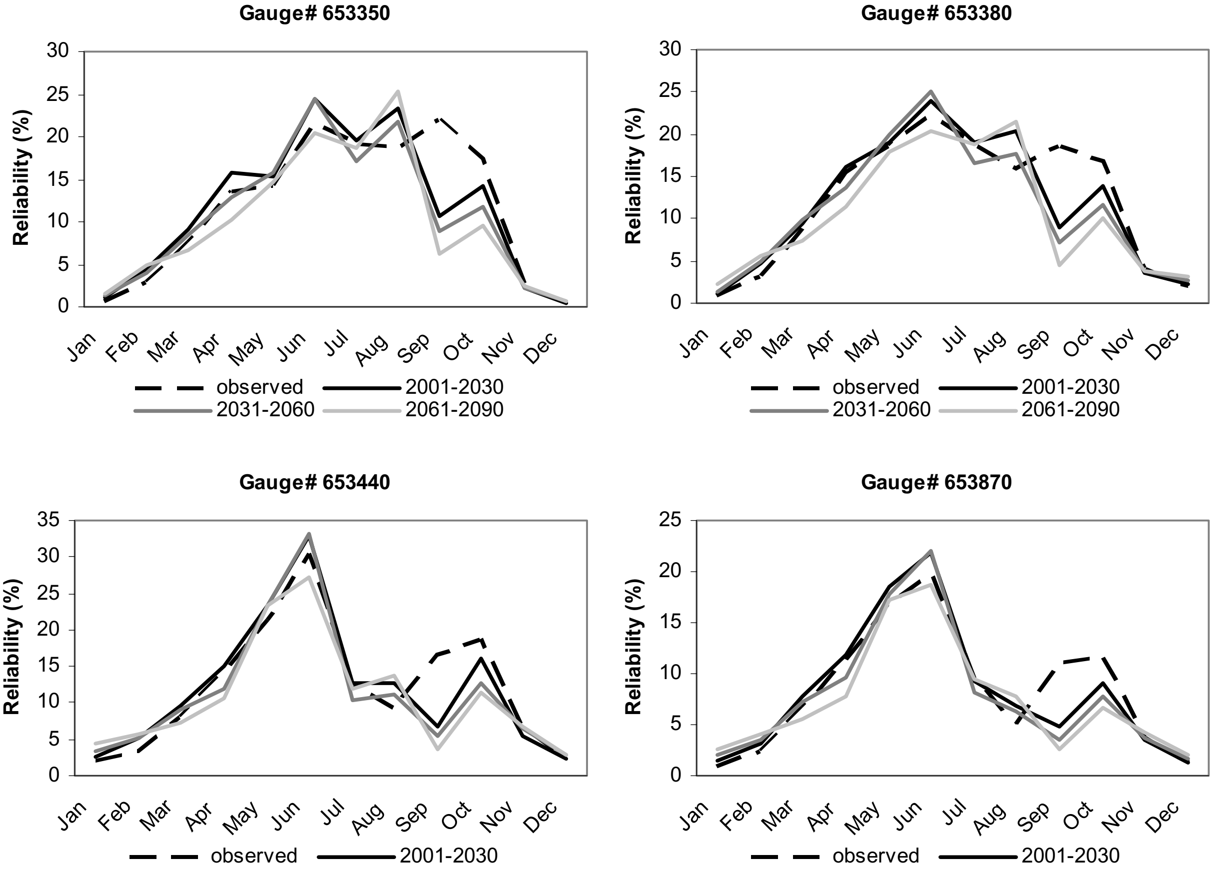

Figure 3: Climate Change Impact on Domestic Rainwater Harvesting Reliability for Four Gauges in the Benin Region.

Figure 3 shows the current reliability of DRWH systems for slum households under the assumption that little, if any, storage is available. This reliability indicates the mean percentage of days in a month in which a person could receive at least 20 L/day. Reliability during the wetter months of the bimodal rainfall pattern range between 20-30%. Figure 3 also reveals the impact of climate change (SRES A2 scenario) on DRWH reliability for the three 30-year periods of the 21st century. Based on these results, little effect on DRWH reliability is expected except during the months of September and October.

DISCUSSION AND CONCLUSIONS

The stochastic rainfall model used in this study performs adequately for this application, though SWGs are known for their under-representation of observed variance. This paper, however, only addresses the climate change impacts on monthly mean DRWH reliability. SWG model overdispersion would have greater impact on DRWH storage systems, as they are dependent on the variability of wet and dry sequences. The storage component of DRWH systems and the assessment of this and other stochastic rainfall models for this region are currently being done. Ultimately, the application of a rainfall model's output should be considered when choosing between models. The simple first-order Markov model seems an ideal choice for quick climate change impact assessments in developing regions where data and resources may preclude more complex rainfall models.

It is clear that under the assumption of little to no water storage, DRWH cannot be used exclusively to provide water to slum dwellers in this region. The enhancement of water supply via DRWH, however, can have important health and social benefits associated with increased hygiene and decreased water fetching time. DRWH can also partially replace water supplies collected from the highly polluted surface waters and shallow ground waters common in impoverished urban communities in the developing world. Under the CGCM3 model, climate change appears to have insignificant impact of DRWH in this area, except for a decrease in the second mode of the seasonal rainfall pattern. This could negatively affect water supplies that need to be sustained into the following dry season.

Obviously, the climate change impacts presented in this study are not definitive. The large uncertainty associated with climate models and forcing scenarios necessitates a thorough multi-model approach. Future work includes the use of several more GCMs, as well as consideration of other greenhouse gas projections. This assessment will also be expanded to include the remaining gauges in the West Africa region. Interpolation of stochastic rainfall model parameters and associated climate change impacts will be another area of future exploration. This will enable a full assessment of DRWH potential in the highly urbanized region. Once this potential is understood, the full health impacts of water supply enhancement can be determined and ultimately made available to decision-makers.

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Future changes in flood hazard in Europe

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Keywords: climate change, extreme precipitation, extreme discharge, flood hazard, Europe.

ABSTRACT

Future climate change will not only bring about changes in the mean climate state, but also in the extremes. To investigate the consequences for flood hazard in Europe, we analysed climate simulations from a recent experiment with the regional climate model HIRHAM. The boundary conditions were derived from the global model HadAM3H/HadCM3 that was forced according to the IPCC emission scenario A2. The experiment consisted of two 30-year time slices corresponding to 1961-1990 and 2071-2100, respectively. These data, with an unprecedented horizontal resolution of approximately 12 km, were used to drive the hydrological model LISFLOOD, which has been developed for operational flood forecasting at the European scale. In this way we were able to simulate river discharge at 5 km grid scale. By means of extreme value analysis we calculated the changes in runoff statistics and flood frequency. The results show an increase in mean precipitation of up to 60% in winter over much of Scandinavia, but a decrease of sometimes more than 50% in summer over most of the Mediterranean, particularly in the Iberian Peninsula. In summer most of Western and Central Europe can also expect much drier conditions. The extreme precipitation levels show a much different and more localized pattern of change, but seem to increase across most of the continent, with the exception of Southern Spain. As a result, the 100-year discharge level increases in many rivers across Europe, even in areas that are generally becoming much drier, such as the Mediterranean region. In most rivers in Northern Europe, though, the extreme discharge levels are projected to decrease, which may be explained by warmer and shorter winters and consequently a reduction in the snowmelt runoff peak in spring.

INTRODUCTION

Simulations with global and regional climate models generally predict that the future climate in Europe will be warmer, that the south will get drier and that Northern Europe will become wetter. Additionally, the precipitation variability is projected to increase in most parts of Europe, with extreme precipitation events becoming more frequent and more intense (Christensen & Christensen, 2003; Beniston et al., 2007; Meehl et al., 2007). Nevertheless, relatively few studies have investigated the associated changes in flood hazard under climate change in Europe. Among those that have appeared in the literature is a geographical preference for catchments located in the UK (e.g. Kay et al., 2006), the Benelux countries (e.g. Booij, 2005), Germany (e.g. Shabalova et al., 2003) and Scandinavia (e.g. Graham et al., 2007a). Some studies found an increase in flood frequency and intensity, while others reported a decreasing trend. The application of different climate scenarios and hydrological models, as well as the basin-specific characteristics make it difficult to compare results of different studies and to draw an overall picture of the effects of climate change on flood hazards at the European scale.

To date, only Lehner et al. (2006) made a pan-European assessment of changes in flood hazard due to climate change and changes in water use. In this study, the authors used the climate signal of two different General Circulation Models (GCMs) to assess changes in flood frequencies and found Northern and North-Eastern Europe to be most prone to a rise in flood hazard. However, they based their analysis on monthly data and a rather coarse grid resolution of 0.5°, and since they used a delta-change approach (i.e. the climate signal is applied to an observation-based dataset), the analysis of Lehner et al. (2006) does not take into account a potential increase in variability.

Due to their coarse horizontal resolution, GCMs are not optimally suited to simulate mesoscale hydroclimatological processes and do not provide sufficient information on the spatial patterns in temperature and precipitation in areas of complex topography and land use. Dynamical downscaling by means of Regional Climate Models (RCM) nested within a GCM therefore has significant advantages over GCM-based scenarios in many impact studies (Christensen et al., 2007). In recent years, the horizontal resolution of RCM simulations has increased considerably and now approaches a level that allows a realistic simulation of the amount and intensity of precipitation at the scale of river basins and small catchments. RCMs can therefore be used to analyse trends in hydrometeorological extremes, although one should be careful about the precipitation biases that most of them show (Graham et al., 2007b).

Within the framework of the PRUDENCE project (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects; Christensen et al., 2007) several RCM simulations have been produced for the European domain at horizontal spatial scales of ~50 km and a few even at ~20 km. In the study presented in this paper we use the results of a recent experiment with the RCM HIRHAM (Christensen et al., 1996) at an even higher horizontal resolution of 12 km. To investigate the impacts of climate change on flood hazard in Europe, these data were used to drive the hydrological model LISFLOOD (De Roo et al., 2000). This model has been developed for operational flood forecasting and is a combination of a grid-based water balance model and a physically-based routing scheme. Here we present some of the first results of the changes in precipitation patterns and extreme discharge events at European scale.

METHODOLOGY

For more information on the two models used in this study, the reader is referred to Christensen et al. (1996) for HIRHAM and to De Roo et al. (2000) and Van der Knijff & De Roo (2006) for LISFLOOD. In the current simulations, HIRHAM was forced by HadAM3H/HadCM3 global climate model for a 30-year control period and a 30-year scenario run corresponding to 2071-2100 according to the A2 emission scenario of the Intergovernmental Panel on Climate Change (IPCC) (Nakicenovic & Swart, 2000). The HIRHAM simulations of temperature, precipitation, solar and thermal radiation, humidity and wind speed data were used to drive LISFLOOD on a daily basis. For this purpose the HIRHAM data were regridded to the 5 km grid scale of LISFLOOD. No further downscaling or altitude correction has been applied because of the absence of high-resolution precipitation datasets with European coverage. Since LISFLOOD is a distributed model, it produces runoff for every grid cell, which is then routed through the river network using a kinematic wave approach. Based on 30 years of daily discharge data, an extreme value distribution (in this case a Gumbel distribution; Gilleland & Katz, 2005) was fitted to the annual maxima, which was then used to estimate extreme discharge levels with a given return period.

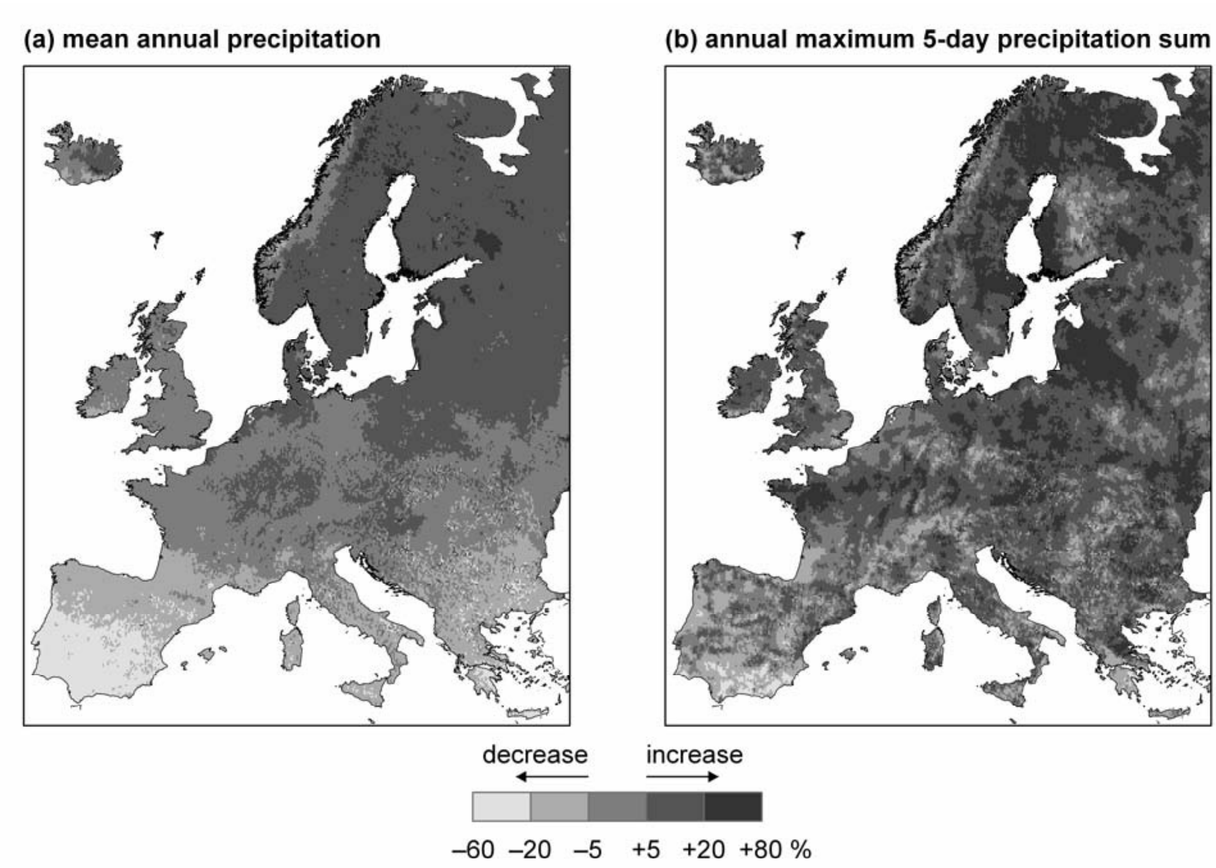

Figure 1. Change in precipitation in the scenario run (2071-2100) relative to the control run, (a) mean annual precipitation, (b) mean annual maximum amount of rain in 5 consecutive days. Simulation of HIRHAM forced by HadAM3H / HadCM3 and IPCC-SRES scenario A2.

RESULTS

The changes in precipitation patterns in the HIRHAM simulation are summarised in Figure 1. The changes in mean annual precipitation (Figure 1.a) correspond with those found with other models (see, e.g., Christensen & Christensen, 2007), that is, a general tendency towards drier conditions in the Mediterranean region and more rainfall over much of Central and Northern Europe. However, in summer the precipitation decreases almost everywhere, including over Southern Scandinavia, while the winter generally becomes much wetter, except in the very south of the continent, as well as the Norwegian coast (not shown). The increase in winter precipitation can be quite substantial, for example in Southern Sweden, where it amounts to more than 50%. In summer, on the other hand, the decline in rainfall can be more than 50% in Southernmost Spain and Portugal. Quite a different pattern can be seen in the extreme precipitation levels, as illustrated by the change in the annual maximum amount of rain falling in 5 consecutive days (Figure 1.b). This maximum 5-day amount is projected to increase across most of Europe. This increase can also be seen in places where the average precipitation is decreasing or not changing considerably, but the pattern is much more localised. Increases in the maximum 5-day amount occur in all seasons, with the exception of the Iberian Peninsula in spring and much of Southern Europe, Western France and the British Islands in summer (not shown).

The corresponding changes in river discharge, as simulated by LISFLOOD, are shown in Figure 2. The average discharge shows a pattern similar to that of the annual rainfall, that is, a decrease in runoff in Southern Europe, an increase in the north and little change in much of Central Europe. Note, though, how the changes in upstream areas (or rather the lack thereof) sometimes get transported downstream, as can be seen, for example in the Lower Danube, Rhone and Rhine river basins.

An almost opposite pattern can be seen in the changes in the 100-year return level – based on the Gumbel distribution fitted to the annual maxima in the discharge time series (Figure 2.b). Over much of Northern Europe the 100-year discharge level is actually decreasing, in spite of an increase in the average runoff. In these areas the peak discharge usually occurs in spring, when the snow pack accumulated during the winter melts away. The decrease in the 100-year return level in these regions is likely due to higher temperatures causing a shorter snow season and less snow accumulation. A similar change can also be seen in, for example, some rivers draining from the Alps and the Carpathian Mountains. Elsewhere in Europe, the 100-year discharge is projected to increase, even in areas where the climate is getting much drier on average, like in Spain and Southern France. This implies that in many rivers in Europe extreme discharge levels may become more frequent and/or more intense. In some major river basins like the Rhone, Rhine, Elbe and the Upper Danube, the probability of a 100-year flood almost doubles, or, in other words, the return period decreases to about 40-60 years. Note also that, while the extreme discharge levels increase in the Upper Danube, the Lower Danube shows a trend towards less extreme discharges and a lower probability of extreme floods (Figure 2.b).

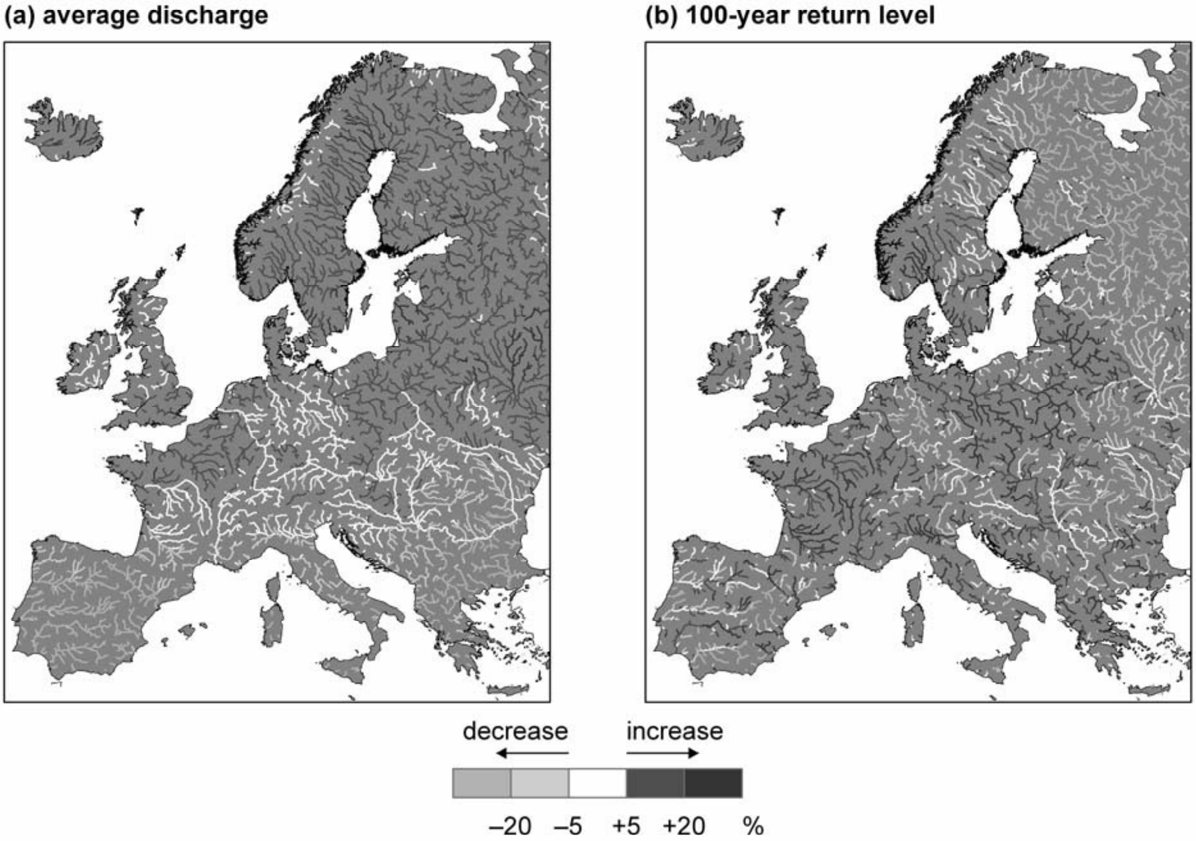

Figure 2. Change in river discharge in the scenario run (2071-2100) relative to the control run, (a) average discharge, (b) 100-year return level as estimated from the Gumbel distribution fitted to the annual maximum discharges. Simulation of LISFLOOD driven by HIRHAM – HadAM3H / HadCM3 and IPCC SRES scenario A2. Shown here are only rivers with an upstream area of 1000 km^2 or more.

DISCUSSION, CONCLUSIONS AND OUTLOOK

The results presented in this paper constitute a first pan-European assessment of flood hazard under future climate change based on very high resolution regional climate modelling, a spatially distributed flood forecasting model and state-of-the-art statistical analysis techniques. In some respects our findings differ from those of earlier studies. For example, over much of Northern Europe we found a reduction in extreme discharge levels and flood risk, while Lehner et al. (2006) predicted an opposite trend (a strong increase) for the same region. Also the IPCC, in its latest assessment report (IPCC, 2007) foresees "more frequent winter floods" in Northern Europe. Our analysis does not *exclude* the possibility of more frequent winter floods in this area, but the general tendency is towards less extreme discharges related to less snow accumulation in winter. Likewise, we find a – sometimes strong – increase in the probability of extreme floods in many rivers in Western and Central Europe that do not show up in the analysis of Lehner et al. (2006), and also in areas that have a general trend towards a much drier climate, like the Iberian Peninsula.

It should be noted, though, that the present analysis is based on only one emission scenario (A2) and one global model (HadAM3H) that was used to provide boundary conditions for HIRHAM. In a recent study, Graham et al. (2007b) concluded that the choice of the GCM has a larger impact on projected hydrological changes than either the emission scenario or the RCM that is used for downscaling, even for a period at the end of this century. It is therefore essential to include more simulations from different global and regional climate models and different scenarios in order to better evaluate the uncertainties in the patterns of change that were found here.

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Climate Change and Integrated Water Resources Management

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ABSTRACT

Climate change is set to inflict damage in every continent, hitting poor countries hardest and threatening nearly a third of the world's species with extinction and the Global warming will affect much of life on Earth in this century. Poor people are the most vulnerable and will be the worst hit by the impacts of climate change. The billions of people will face water scarcity and hundreds of millions will likely go hungry, mainly in the poorest regions least to blame for causing the problem. Poor tropical countries will be worst hit.

It is internationally recognized that Bangladesh may suffer the most severe impacts from climate change, since the country is low-lying, located on the delta of the Ganges, Brahmaputra and Meghna and densely populated. The mighty rivers Ganges, Brahmaputra and Meghna's basins are international and the approach should be taken for regional sustainable and integrated water resource management involving all co riparian countries. The principle of low flow in the international rivers during all seasons should be ensured. Energy sector should be integrated with water. Indian River Linking project involving international rivers should be seriously discussed at all levels. Recent news of using Ganges water at Farakka to generate power in India is alarming since India has not consulted Bangladesh although water available for Bangladesh is dwindling thus threatening river based ecosystems and livelihoods of millions of people. To ensure effective Integrated Water Resources Management and Water Conservation, establishment of institutions for preparing integrated water resources plans at local levels with effective involvement of local governments, preparing master plans for specific issues such as river training, establishing and operating regulatory mechanisms for water quantity and quality management including standards for effluent disposal and floodplain zoning are necessary.

In the Bangladesh Poverty Reduction Strategy (PRSP), Millennium Development Goals and other donor driven initiatives, two vital areas linked with poverty and ecosystem survivality seem to be either missing or being neglected: a) Trans boundary water use and b) coastal area poverty and critical ecosystems vulnerable due to climate change. Since the World Summit on Sustainable Development (WSSD) goals and PRSP are integrated, it is necessary that the country's WSSD goals and PRSP should also be in harmony.

INTRODUCTION

One of the most critical challenges Bangladesh faces is the management of water resources during their excesses and acute scarcity. It is particularly difficult when only 7% of the catchments areas of the very international rivers, the Ganges, The Brahmaputra and the Meghna are in Bangladesh while 97% is outside Bangladesh where unfortunately, Bangladesh has no control on upstream diversion and water use.

India and Bangladesh has attempted to cope with this particular issue through a series of bilateral interim water sharing agreements since 1977. The 1996 Treaty stipulates the water sharing arrangements of the Ganges in the 30-year period; but it does not provide a long-term guaranteed minimum flow to Bangladesh, as the flow of water in the Ganges is subject to abstractions by upstream Indian states, which may further intensify in the event of rapid economic growth there. There is no water sharing agreements for other trans-boundary rivers.

The UN Conference on Environment and Development in its Agenda 21 emphasizes the importance of Integrated Water Resource Management (IWRM). The core point of IWRM is that is development of all aspects of entire basin in a basin wide approach, that all relevant agencies of the government and water users must be involved in the planning process and that the goal should be use of water resources in a manner that is sustainable, taking into account environment protection, economic development and social well-being. Friendly countries and United Nation are to come forward to the aid of Bangladesh’s water problems. No PRSP will be complete without identifying the present trends and tools available to solve the problems.

Climate Change: Climate change would cause severe damage in every continent, hitting poor countries hardest and threatening nearly a third of the world's species with extinction and the Global warming will affect much of life on Earth in this century, the UN's Intergovernmental Panel on Climate Change (IPCC) said in their latest landmark report published in April this year. Damage to Earth's weather systems from greenhouse gases will change rainfall patterns, punch up the power of storms and boost the risk of drought, flooding and stress on water supplies, the IPCC said.

The consequences will be adverse or in some scenarios even catastrophic, depending chiefly on how much carbon gas is spewed into the atmosphere from burning oil, gas and coal. Poor people are the most vulnerable and will be the worst hit by the impacts of climate change. Up to 30 percent of animal, plant and species will be vulnerable to extinction if global temperatures rise by 1.5-2.5 degrees Celsius (2.7 to 4.5 Fahrenheit). It is very likely that all regions will experience either declines in benefits or increases in costs for increases in temperature greater than 2 to 3 degrees (C), or 3.6-5.4 F, over 1990 levels, according to a summary for policymakers agreed by the IPCC.

The summary accompanies a massive 1,400-page report that said there was now clear evidence that climate change was already happening, through loss of Arctic ice, mountain glaciers, thawing permafrost and other recently observed phenomena. Martin Parry, co-chair of the IPCC's working group, said, "the doubt has been removed" that climate change was already on the march. "On all continents there is a climate change signal, it is affecting animals and plants and on a global level too," he said.

Bettina Menne, a World Health Organisation (WHO) specialist who was lead author on the chapter of health, said 150,000 deaths could be "attributed directly" to climate change in 2000 alone, due to malnutrition and diarrhea.

Looking to the future, the main report predicts that billions of people will face water scarcity and hundreds of millions will likely go hungry, mainly in the poorest regions least to blame for causing the problem. Poor tropical countries will be worst hit, it says.

Worsening water shortages in thirsty countries, malnutrition caused by desiccated fields, property damage from extreme weather events and the spread of disease by mosquitoes and other vectors will amount to a punishing bill that is beyond the ability of vulnerable countries, especially in Africa, to pay. Biodiversity and natural habitat are in for a hammering.

Even a modest increase in temperatures will bleach many coral reefs; reduce part of eastern Amazonian to a parched savannah, thaw swathes of the northern hemisphere's permafrost and change seasons for plant pollination and animal reproduction.

Green groups sounded the alarm, demanding immediate action to tackle fossil-fuel emissions and help poor countries to cope with the threat. "This is a glimpse into an apocalyptic future," said Greenpeace International's Stephanie Tunmore. "The Earth will be transformed by human-induced climate change, unless action is taken soon and fast." "It is a looming humanitarian catastrophe, ultimately threatening our global security and survival," said Friends of the Earth's Catherine Pearce. The IPCC in its previous report concluded, “The balance of evidence suggests a discernible human influence on global climate”.

Bangladesh’s vulnerability: Indeed, it has internationally been recognized that Bangladesh may suffer the most severe impacts from climate change, since the country is low-lying, located on the delta of the Ganges, Brahmaputra and Meghna and densely populated. There are many tributaries and distributaries of these rivers and in total 57 rivers pass through the country. These rivers drain a total area of 1.72 million square kilometers in India, China, Nepal, Bhutan and Bangladesh.

With the basin’s runoff heavily concentrated in the monsoon season, there has been an increasingly severe competition on the use of the dry season flows in particular in the Ganges River over the past several decades. This is mainly associated with the increased abstraction of water in the upstream regions of the basin in India. As a result, the dry season flows of the Ganges entering into Bangladesh have reduced substantially, and significant environmental changes have been reported in its Southwest region that includes the Sundarbans, the largest Mangrove Forest in the world, which comprises an area of about 577,000 ha. Change in climate shall have serious impacts on the mangrove forests. The rise in sea level and availability of less fresh water particularly during winter when rainfall will be less will cause inland intrusion of saline water. As a result, many mangrove species, intolerant of increased salinity, may be threatened. In addition, the highly dense human settlements just outside the mangrove area will restrict the migration of the mangrove areas to less saline area. The Sundarbans may be completely inundated by a 1m rise in sea level. Increase in temperature and sea level rise will seriously affect the Sundarbans' ecosystem and bio-diversity. The area may shrink and many flora and fauna species may face extinction. A wide range of mammals, birds, amphibians, reptiles, crustaceans, and above all the Royal Bengal Tiger will face extinction. More importantly, the boundaries of Sundarbans will have worse effect.

Bangladesh’s economy strongly depends on agriculture and natural resources that are sensitive to climate change and sea level rise. The confluence of world’s two largest rivers, the Brahmaputra and the Ganges in Bangladesh, together with numerous other rivers interlaces Bangladesh with over 24000 km of river channels. During the annual monsoon the catchments areas for the Brahmaputra and Ganges, 93% of which lie outside of Bangladesh, receive very intense rainfall. Despite the extensive river system, consisting of approximately 230 significant rivers, the rainfall is not effectively drained through Bangladesh and severe overland flooding usually occurs.

Effects of CCSLR: While Bangladesh is already perspiring with catastrophic disasters like tropical cyclones, storm surges, floods, droughts and erosion, in the foreseeable future, the country is likely to be affected by the biggest ever, long lasting and global scale human-made disaster, i.e. the climate change and the sea level rise (CCSLR). The geographical location, low and almost flat topography, very high population density, etc. have made Bangladesh one of the most vulnerable countries of the world to be affected by CCSLR.

Regional water management: All should give the recognition of Ganges Brahmaputra and Meghna as international Basins and the approach should be taken for regional sustainable and integrated water resource management involving all co riparian countries. The principle of low flow in the international rivers during all seasons should be ensured. All stakeholders should have a say and work towards regional cooperation in the water sector as a top priority. Energy sector should be integrated with water. Indian River Linking project involving international rivers should be seriously discussed at all levels including the parliament so that voice of Bangladesh is concerted and information shared by all concerned. The forum of SAARC should be used and development partner’s cooperation should be sought. Recent news of using Ganges water at Farakka to generate power in India is alarming since India has not consulted Bangladesh although water available for Bangladesh is dwindling thus threatening river based ecosystems and livelihoods of millions of people.

Bilateral treaty: Bangladesh has Treaty with India but the Treaty provisions are not being honored. At present India is building another hydro electricity plant on Barak River in India above Sylhet district without sharing information or consulting with Bangladesh. It will have far-reaching impact in the entire North East and South Eastern part of Bangladesh as the country is already experiencing in her North West and South West part due to Farakka dam on the Ganges. No amount of aid will be able to mitigate the suffering of the people, economy, agriculture and environment if one after another common rivers are diverted unilaterally. Water should be included in all peace and development talks with India and other neighbors.

Drainage congestion: The huge sediment loads brought by three Himalayan rivers, coupled with a negligible flow gradient add to drainage congestion problems and exacerbate the extent of flooding. Bangladesh’s very high population and population density further enhance the societal exposure to such risks. Many projected climate change impacts including sea level rise, higher temperatures (mean temperature increases of 1.4°C and 2.4°C are projected by 2050 and 2100 respectively), vapor-transpiration losses, enhanced monsoon precipitation and run-off, potentially reduced dry season precipitation, and increase in cyclone intensity would in fact reinforce many of these baseline stresses that already pose a serious impediment to the economic development of Bangladesh.

Some critical impacts of climate change that Bangladesh will face are drainage congestion problems due to higher seawater levels, subsidence, siltation of estuary branches, higher river bed levels and reduced sedimentation in flood protected areas, reduced fresh water availability due to growing demands stimulated by climate changes (through increased vapor-transpiration), population growth and economic development, disturbance of morphological processes such as increased bank erosion and bed level changes of rivers and estuaries also Disturbance of the balance between river sediment transport and deposition in rivers, flood plains and coastal areas, increased intensity of disasters (extreme events) ncluding cyclones/storm surges, floods and droughts.

Threat to sustainable development: In Bangladesh, climate change posses a major threat to sustainable development. Rather than being mutually exclusive, adapting to climate change should be seen as a requirement for sustainable development. A study done by World Bank illustrates key risks from climate change and the necessary strategic adaptation. It is written to help stimulate thinking among development and climate sensitive sector experts and planners in the Bangladesh Government, the Bank, and the rest of the donor community. The study concluded with urging the need for far greater emphasis on knowledge based integrated planning and decision-making, and a greater focus on monitoring and provision of reliable data. With this strategic move, there are feasible ways to adapt to climate change.

Adaptation: The question is whether and how Bangladesh can adapt to the changes. What is important to remember is climate change should be a consideration when development and other decisions that affect the capacity of climate sensitive systems to cope with this phenomenon are being made. Bangladesh should adopt anticipatory rather than reactive strategy to climate change.

Adaptations of climactic factors such as negotiating water sharing arrangements and participating in international deliberations on the mitigation of greenhouse gas emissions. The goal of anticipatory adaptation measures is to reduce vulnerability by minimizing the negative impacts of climate change, or enabling reactive adaptation to come about more efficiently. Reducing vulnerability is directed towards making the system (both resources and users) more robust and flexible to changes. The concrete and practical possibilities to decrease the country's vulnerability to climate change by distinguishing various types of adaptation measures.

Physical adaptations (protection and enhancement) in the human made or natural systems, such as: planting of mangroves, raising of dikes, construction of new infrastructure such as cyclone shelters and or coastal embankments, landfills and tidal basins.

Institutional adaptations would facilitate the various types of adaptation. These may also include socio-economic measures such as changing the use of resources through non- structural measures, such as, crop diversification and sustainable shrimp cultivation, changing planning procedures and increasing awareness level, research and information management etc.

Indigenous knowledge: Nevertheless, Bangladesh should apply its indigenous knowledge and its own resources for adaptation process, which they have acquired through hundreds of years because; the land/people ratio in this country is much higher then anywhere in the world. So, what can be implemented in Brazil may not appropriate for Bangladesh. Carbon trading may be suitable for some African countries considering their socio-economic conditions but Bangladesh should take this step more cautiously. In this regard, it is necessary to form small groups of more likely countries from Group-77. This will be more helpful for Bangladesh for climate change adoption. In addition, the experts in Bangladesh can form groups to spread this indigenous knowledge to the countries that are observing natural disasters recently like Florida, Mexico, Japan, India, Indonesia, Canada and Brazil. Costs involved and required in institutional arrangements often pose a set of serious constraints. Proper coordination and management require operational procedures, which are often lacking in Bangladesh, and are hard to finance.

WSSD goals and PRSP: In the Bangladesh Poverty Reduction Strategy (PRSP), Millennium Development Goals and other donor driven initiatives, two vital areas linked with poverty and ecosystem survivality seem to be either missing or being neglected: a) Trans boundary water use and b) coastal area poverty and critical ecosystems vulnerable due to climate change. Since the World Summit on Sustainable Development (WSSD) goals and PRSP are integrated, it is necessary that the country's WSSD goals and PRSP should also be in harmony.

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While Bangladesh is already suffering from major extreme events, and is relatively well equipped in disaster response (with the continuous process of improving on its capacity to mitigate the impacts of cyclones and riverine floods etc), the country lacks the capacity and mechanism to account for long-term changes. There remains a serious lack of real time data in monitoring and preparing for these events. Considering the country's fewer financial resources, lacks of institutional, planning and decision-making structures, inefficient management of resources, lack of awareness to both planning agencies and public, most of all unhealthy, less educated and technically competent population it is reasonable to take cost effective, new technologies for adaptation of climate change impacts.

In accordance with institutional arrangements, concrete actions to reduce Bangladesh's vulnerability to climate change should urgently be taken. There is also a very urgent need of setting up an International Disaster management Centre in Bangladesh. In addition, to mitigate the climate change developed countries can trade carbon with developing countries. Experts estimate that Bangladesh can gain 6 billion USD by Carbon Trading. In this case, government can seek technological help from Bangladeshi scientists in home and abroad.

Environmental flows: An environmental flow is the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated. Environmental flows provide critical contributions to the health, economic development and poverty alleviation. In the context of both transboundary rivers and within country wetland, rivers and coastal area the principle of environment flow should be followed for sustainable water resource development.

Environmental flows are an integral part of modern management of transboundary and river basin and therefore should be an integral part of PRSP and National Water Policy.

National Water Policy: A milestone in formulating policy and planning for the water sector was the adoption of the National Water Policy (NWP) in 1999. This was done after some consultation with stakeholders, related sector agencies, NGOs, the civil society and major donors. The NWP examined all water related issues of the country embracing multiple sectors such as agriculture, fisheries, environment, forestry, land, industry navigation etc. and provided guidelines for development, utilization and management of water in an integrated manner. The NWP also defined major institutional reform and the role of the government (including the decentralization and transfer of water resources management schemes), the private sector and the civil society in the management of water. The NWP has called for accelerating the development of sustainable public and private water delivery systems with appropriate legal and financial measures and incentives including formulation of water rights and water pricing.

In line with NWP, a National Water Management Plan (NWMP) has been prepared to provide a framework guiding principles for future approaches and investments for water resources management in the short to long-term. The principal feature of the NWMP is its focus on integrated water resource management. Water policies and plans given the country's priorities and indicate how those priorities could be achieved, but the institutions are the tools to realize them.

Regulatory Framework: Water sector institutions, like other sectoral institutions, should have a legal and regulatory framework under which they will operate. Existing laws and regulations in Bangladesh do not cover all these area. To provide a framework for water abstraction, licensing for water extraction, administering water rights in designated water scarcity zone, water quality management and pollution control and demand management, a draft water act was being formulated. As this legislation, process is in progress, administrative machinery and procedures for administering the law should be designed. Existing institutions, such as Ministry of Water Resources-MOWR, The Water Resources Planning Organization-WARPO, Bangladesh Water Development Board-BWDB, Local Government Councils, and local civil administration, needs to be reviewed to evolve a system for administering the water act.

CONCLUSION

To foster Integrated Water Resources Management and Water Conservation, establishment of institutions for preparing integrated water resources plans at local levels with effective involvement of local governments, preparing master plans for specific issues such as river training, establishing and operating regulatory mechanisms for water quantity and quality management including standards for effluent disposal and floodplain zoning are necessary.

To improve governance steps for (a) improving resources, management infrastructure, and organizational vision and strategy of sector agencies; (b) promoting the same for local governments while defining appropriate roles, functions, and authorities; (c) strengthening anticorruption efforts through strengthening of internal and external quality control for infrastructure and other administrative systems, and (d) improving regulatory framework of Water agencies and provide annual social, technical, and financial audit are necessary.

The Global Precipitation Climatology Centre (GPCC) – a European Centre supporting Water Resources and Climate Change Assessment

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ABSTRACT

The Global Precipitation Climatology Centre (GPCC) hosted by the Deutscher Wetterdienst (DWD) since year 1988 upon request of the World Meteorological Organisation (WMO) is a German contribution to the World Climate Research Programme (WCRP) and to the Global Climate Observing System (GCOS). Main GPCC task is the analysis of the spatial and temporal distribution of land-surface precipitation on a monthly time-scale based on *in situ* raingauge data.

Since the last conference on Climate and Water (CAW) in year 1998, the GPCC observational climate data base has been significantly enlarged and further complemented with regard to spatial as well as temporal coverage. Monthly precipitation data from many different WMO (World Meteorological Organisation) member countries have been received and processed into the GPCC Data Base. The GPCC highly appreciates the assistance by all the countries having supplied observed precipitation data. Additionally the integration of the historical precipitation databases of CRU (Climate Research Unit of the University of East Anglia, UK), FAO (UN Food and Agricultural Organisation) and GHCN (Global Historical Climatology Network, USA) into the GPCC data base has been finished. GPCC has now the largest global monthly precipitation station database of the world (data from more than 60 000 different stations in more than 170 countries of the world).

All four different GPCC analysis products result from the same quasi-operational data management and analysis system. However, depending on the user requirements, esp. regarding timeliness and quality, they differ with regard to the number of the stations included and the level of data quality control being performed. Recent research activities supported the preparation of a 50-year precipitation climatology, used for assessment of precipitation variability and trends in the 2007 report of the Intergovernmental Panel on Climate Change (IPCC). A new version of the GPCC Full Data Reanalysis, based on a significantly enlarged database, and a new global precipitation climatology, will be produced until summer 2007.

INTRODUCTION

Precipitation is the main input parameter for the global water cycle. Its global and regional distribution is one of the driving forces for our climate. Precipitation variability and changes on different spatial and temporal scales, leading to floods and droughts, significantly impact our environment, economy and society.

GPCC provides precipitation analyses for climate monitoring and research based on the largest monthly precipitation station data base of the world (more than 60 000 stations in more than 170 countries of the world). Its products, accessible free of charge via internet, are adjusted to the needs of different user communities and contribute to water resources assessments, flood and drought monitoring, climate variability and trend analyses.

Specific user requirements related to precipitation climatology products produced by GPCC are:

- Timeliness e.g. for drought monitoring;

- High resolution e.g. for regionally structured global maps;
- High accuracy e.g. for verification of models and water cycle assessment;
- Homogeneity e.g. for climate variability and change studies.

THE GPCC DATA BASE

The accuracy of raingauge based precipitation analyses mainly depends on the number of stations being used. In order to calculate monthly area-mean precipitation on 2.5° gridboxes with a sampling error of not more than 10%, between 8 and 16 stations per gridbox are needed (WMO 1985, Rudolf et al. 1994). To cover the global land-surface by gridded data of this accuracy, this requirement adds up to 40,000 equally distributed stations worldwide. Fig. 1 shows the spatial distribution of stations with at least 10 years of data in the GPCC data base.

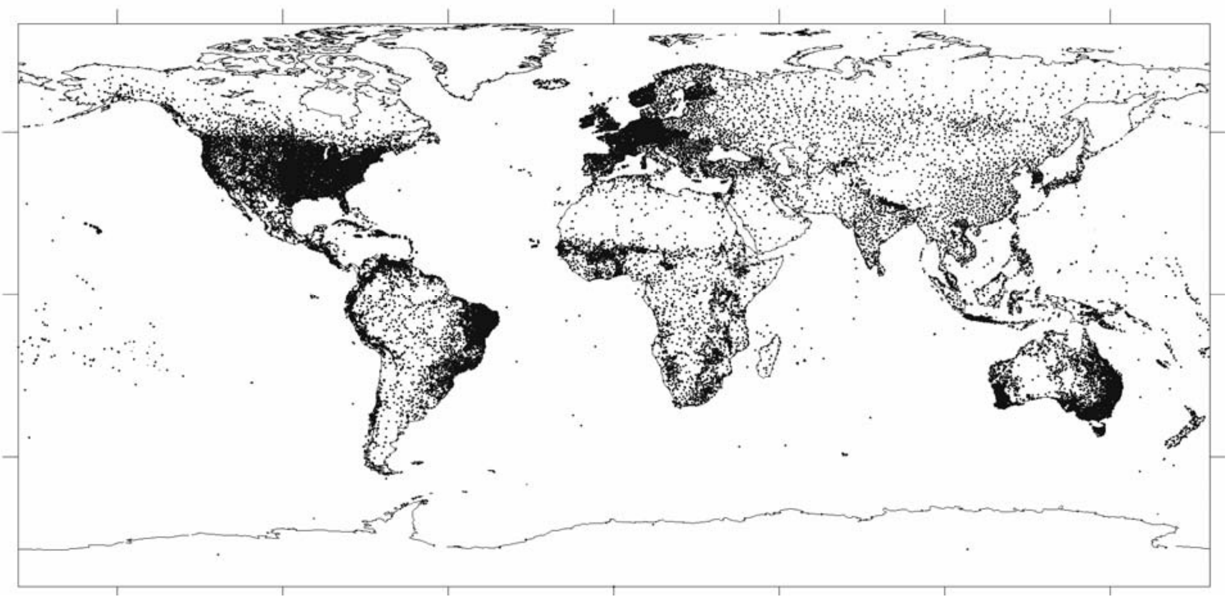

Figure 1: Spatial distribution of monthly in situ precipitation stations with at least 10 years of data in GPCC Data base (Total number of stations in July 2006: 43028)

GPCC distinguishes two types of observed precipitation data with regard to their timeliness: data available near real-time (based on synoptic weather observation data continuously exchanged among the national meteorological services via the Global Telecommunication System of WMO), and additional data which can be obtained with a larger time delay only.

GPCC near real-time data base
The data base for GPCC's Monitoring Product is merged from three sources: monthly precipitation totals derived from synoptical weather reports (SYNOP) at the DWD, Germany, and at NOAA/NCEP, USA, and monthly precipitation totals extracted from CLIMAT-bulletins received at the DWD. The near real-time available data base comprises around 7,500 stations and provides in some regions a sufficient data base for quantitative precipitation estimates, if the grid resolution is not too high. Users are advised to carefully take into account the number of stations per grid, which is provided as additional information to every GPCC product. Within the data pool, the CLIMAT data are of higher quality and provide a reference for quality assessment of the SYNOP-based data. The GPCC First Guess Product only includes the DWD SYNOP-based monthly precipitation totals from around 6,000 stations.

GPCC Full data base
With respect to the limited real-time availability of raingauge data, additional data from dense national observation networks of individual countries are collected at the GPCC. The data acquisition is supported by recommendation letters of the WMO. So far, National Meteorological and/or Hydrological Services (NMHSs) from more than 170 countries of the world contributed data to the GPCC. How-

ever, the delay of the deliveries varies between 1-5 years or even more due to the processing time needed by the originators. In addition, other available global and regional collections of precipitation station data (GHCN, CRU, FAO, etc.) have been integrated in the GPCC data base. Thereby GPCC has compiled the most comprehensive global collection of monthly precipitation data from *in situ* observations. With respect to the interests and conditions given by the originators (NMHSs), the GPCC cannot redistribute the station related precipitation data to other parties.

The temporal data coverage of the GPCC products is illustrated by Fig. 2. For the near-realtime GPCC Monitoring Product all SYNOP and CLIMAT data are used if available within one month after observation. The Full Data Reanalysis Product includes all data being supplied later by the individual countries. The year with the best data coverage is 1987 with data for 45,000 stations. A gradual decrease of the number of stations from more than 40,000 in 1986-1991 down to 7,500 stations after 2006 is caused by the delay of the delivery to and by post-processing at GPCC. The data base continuously increases by delivery of updates for recent years, supplements with additional stations and complementation by long time-series of data (see „new Data“). GPCC will update its non real-time products every 1-2 years, both non real-time products will be updated until end of year 2007.

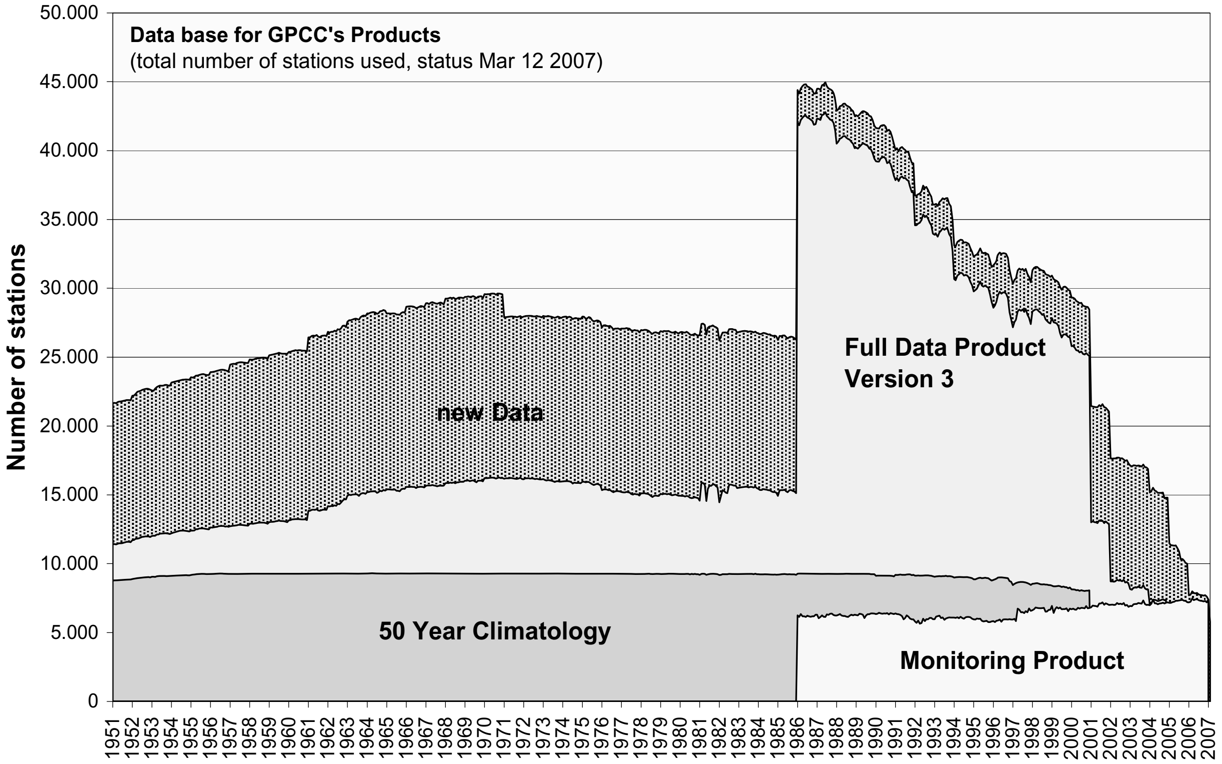

Figure 2: Total number of stations used for the three GPCC products (Near realtime Monitoring Product, homogeneous 50 Year Climatology (Version 1.1), Full Data Reanalysis Product (Version 3) and “new data” processed since January 2005.

THE GPCC DATA PROCESSING SCHEME

All data reaching the GPCC are checked, processed and integrated in a Relational Data Base Management System. Within this data bank, the records from the different sources (SYNOP, CLIMAT, national data etc.) are stored in parallel under addition of quality flags indicating the results of data processing. By this comparison and cross-check of data from different origin is possible.
The data processing steps include quality-control and harmonization of the meta data (station identification), quality-assessment of the precipitation data, selection and intercomparison of the data from the different sources for the particular products, interpolation of the station-related data to a regular mesh system, and calculation of the spatial means on the 2.5° respectively 1.0° latitude/longitude gridbox area. The Full Data Reanalysis as well as the 50 Year Climatology are also available in 0.5° resolution.

The basic information about the methods used is published by Rudolf et al. (1994) and Rudolf and Schneider (2005), additional information is given on GPCC's website (http://gpcc.dwd.de).

The near-realtime Monitoring Product and the non-realtime Full Data Reanalysis Product provide the following variables calculated on the grid:

- Monthly precipitation totals for the individual month
- Mean monthly precipitation totals for the period 1961-1990 ("normals")
- Monthly precipitation anomaly i.e. deviation from the mean 1961-1990
- Monthly precipitation percentage related to the mean 1961-1990
- Number of gauges used per gridcell for the individual month
- Systematic gauge-measuring error per gridcell for the individual month (since year 2007 available)
- Fraction of liquid and solid precipitation in % of total precipitation per gridcell for the individual month (since year 2007 available)

THE GPCC PRODUCTS

- The **First Guess Product** of the monthly precipitation anomaly is based on interpolated precipitation anomalies from about 6,000 stations worldwide. Data sources are synoptic weather observation data (SYNOP) received at DWD via the WMO Global Telecommunication System (GTS), and the climatic mean (1961-1990) monthly precipitation totals at the same stations which are extracted from the GPCC global normals collection. An automatic-only quality-control (QC) is applied to these data. Since September 2003, a GPCC First Guess monthly precipitation analysis is available within 5 days after end of an observation month. Main application purpose is to serve as input for near-realtime drought monitoring applications. Figure 3 illustrates a drought monitoring application based on GPCC First Guess analyses;

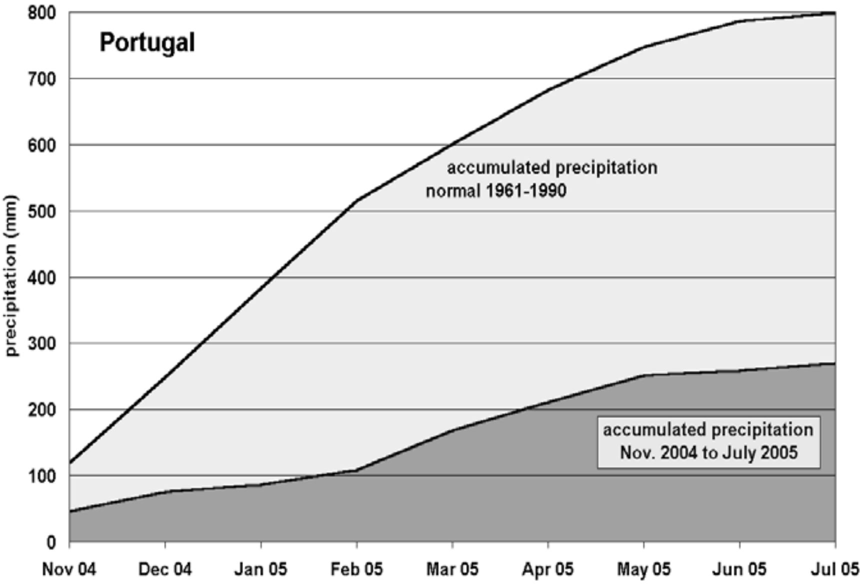

Figure 3: Accumulated precipitation totals (based on GPCC First Guess) and accumulated GPCC precipitation normals 1961-1990 indicating an increasing precipitation deficiency in year 2005 in South West Europe

- The **Monitoring Product** of monthly precipitation for global climate monitoring is based on SYNOP (after high level QC) and monthly CLIMAT reports near-realtime received via GTS from about 7,500 stations and is available within about 2 months after observation month. This is the GPCC product with the longest history: Operational monthly analysis started with year 1986 and has continuously been done every month since then. The analyses are based on intensive automatic and manual quality control of the input data. The GPCC Monitoring Product is the *in situ* component to the satellite-gauge combined precipitation analyses of GPCP (Huffman et al. 1995, Adler et al. 2003) and of CMAP (Xie and Arkin 1997). It also supports regional climate monitoring.

- The **Full Data Reanalysis Product** is of much higher accuracy compared to the GPCC near-real-time products mentioned above. Therefore, its application is recommended for hydrometeorological model verification and water cycle studies, e.g. in context of UNESCO, GEWEX, and GTN-H (Global Terrestrial Network for Hydrology). This analysis product is based on all stations, near-realtime and non-realtime, in the GPCC data base supplying data for the individual month. The data coverage varies from less than 10,000 to more than 43,000 stations. The full data re-analyses are updated at irregular time intervals with respect to significant data base improvements. The current Full Data Reanalysis Product Version 3 covers the period from 1951 to 2004 (see example at Figure 4).

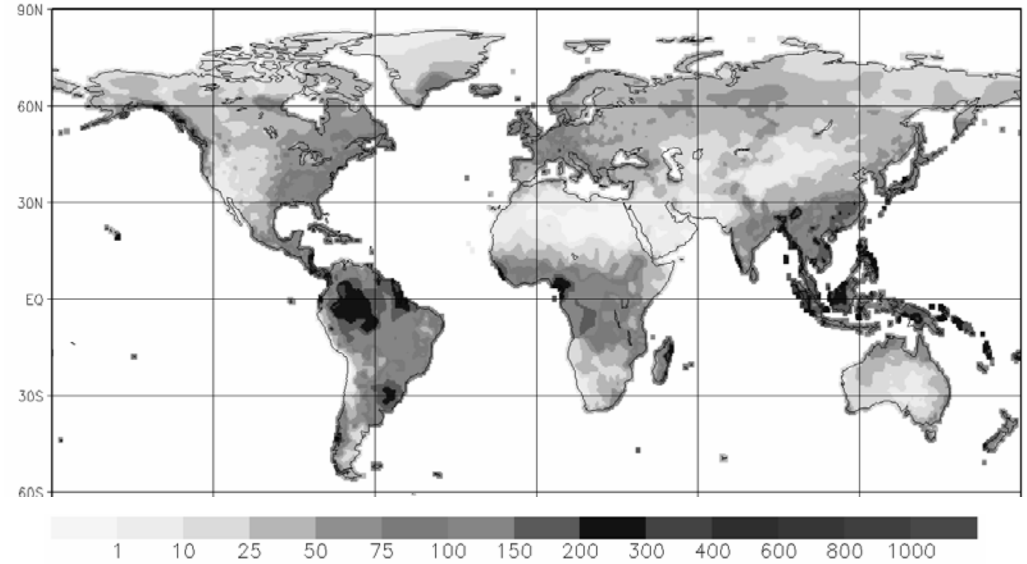

Figure 4: Total Precipitation on earth's landsurface for year 2002 in mm/month (based on GPCC Full Data Product, 0.5° x 0.5° resolution).

- The **50 Year Climatology** VASClimO supplying gridded time-series of monthly precipitation for studies on climate variability and trends is based on data being selected with respect to a (mostly) complete temporal data coverage and homogeneity of the time-series. The current version 1.1 is based on time-series of 9,343 stations covering the period 1951-2000 (Beck, Grieser and Rudolf, 2005). These long-term climatological analyses of homogenised area-averaged precipitation time-series are of special interest for CLIVAR and GCOS and supported the Intergovernmental Panel on Climate Change (IPCC) Working Group I Fourth Assessment Report (FAR) 2007.
- The **Monthly Precipitation Normals Data Set** provides gridded mean monthly total precipitation for the period 1961-1990, based on data from about 30,000 stations. The data base comprises the normals collected by WMO, and normals delivered by the countries to the GPCC or calculated from data time-series available in our database. GPCC is currently working on a new global monthly precipitation climatology based on our significantly enlarged database (more than 60,000 different stations worldwide, of which more than 43,000 stations have at least 10 years of data – see also Figure 1). The new GPCC precipitation climatology is expected to be ready by summer 2007 and will replace the currently used precipitation normals data set.

Access to GPCC's gridded products
The different gridded monthly precipitation data sets of GPCC as well as the GPCP Version 2 Combined Data Set are freely available. They can be easily visualized or downloaded in ASCII format using the GPCC-Visualizer from the GPCC website http://gpcc.dwd.de.

OUTLOOK

The significant enlargement of GPCC's monthly precipitation data base by inclusion of all major global precipitation databases enables the GPCC to produce a new mean precipitation climatology (period mainly 1961-1990) based on the largest monthly precipitation station data base of the world (more than 60.000 different stations). This new climatology, expected to be ready by summer 2007, will support to change the GPCC analysis method from analysing total precipitation amounts to the analysis of relative anomalies based on this new background climatology.

The quasi-operational products of GPCC (First Guess, Monitoring Product) and the Full Data Reanalysis are expected to be significantly improved by this change in the GPCC analysis method. Also an improvement of the VASClimO 50-Year Climatology will be backed by this activity since VASClimO was calculated as relative anomalies from a background climatology based on ca. 26,000 stations; the new climatology will be based on climatological normals from about 50.000 stations. Another positive side effect of the new climatology on the quality of the GPCC products will be a better representation of orographic rainfall effects. The high number of stations is expected to lead to a better station distribution in different altitudes. Interpolation methods to directly take into account the impact of station altitude and orientation related to orography were tested during 2006, however they did not show potential for operational applicability on a global scale by GPCC.

The GPCC kindly requests all responsible national agencies to follow the WMO call and to provide the GPCC with the required precipitation and meta data. The analysis results are of high importance e.g. concerning the verification of global climate models and climate variability studies based on observed data. The analysis results of the GPCC are published and freely accessible. But the station-related data delivered by the countries will not be distributed to third parties, in order to respect and protect the ownership of the originators.

A special thank is addressed to the data contributors, which mostly are National Meteorological and Hydrological Services of the world but also some other institutes. Their data contributions enable the GPCC to do its global precipitation analyses described in this document.

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A comparison of regional approaches to the frequency analysis of extreme precipitation events in Slovakia and Czech Republic

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ABSTRACT

The L-moment-based regionalization technique developed by Hosking and Wallis is the most frequently used tool in regional frequency modelling of heavy precipitation events. The method consists in delineating fixed (but not necessarily spatially contiguous) homogeneous regions, which may, however, lead to undesirable step-like changes in growth curves and design value estimates at a transition from one region to another. Unlike the standard methodology, the region-of-influence (ROI) approach does not make use of a fixed structure of regions but each site has its own ‘region’, i.e. a group of sites that are sufficiently similar to the site of interest. The current study is one of the first attempts to develop the ROI method into the estimation of probabilities of heavy precipitation. Since long-lasting precipitation events usually involve a considerable potential for flood risk, the paper focuses on the frequency analysis of heavy 5-day precipitation amounts observed in warm season. Various settings of the distance metric and regional weighting factors are evaluated, and a comparison of the results with findings of the standard regional frequency analysis over the areas of the Czech Republic and Slovakia is performed. The advantages of the ROI approach are assessed by means of simulation studies. An alternative of the ROI approach based on site statistics appears to be superior to other regional frequency models in Slovakia and comparable to the conventional regional analysis in the Czech Republic; further data sets need to be examined to support and refine the conclusions.

INTRODUCTION

Information on *design values* (quantiles) of heavy one-day and multi-day precipitation amounts is important in various fields of water resources engineering. It is undisputed that the most efficient way to assess reliable estimates of design values is the regional frequency analysis that makes use of simultaneous analysis of several sites in a region that exhibit similar probability distribution curves of extremes. Nowadays, a generally accepted guideline to the regional frequency analysis is the *regional L-moment algorithm* (Hosking and Wallis, 1997).

An initial step of the majority of the regional approaches is a delineation of groups of sites with a fixed (but not necessarily spatially contiguous) structure. A drawback of a choice like that is undesirable step change of variables and estimated quantiles that may occur on boundaries of pooling groups. Such deficiencies are eliminated in the *region-of-influence* (ROI) *method* (Burn, 1990). Its main idea is that there is no need to delineate fixed boundaries between the pooling groups but rather they are defined in a flexible way. It means that each site has its own ‘region‘, a unique set of sufficiently similar stations, from which extreme precipitation information is transferred to the site of interest. The similarity of sites is evaluated by a properly chosen set of site attributes.

Up-to-now, the ROI method has been used in connection with *flood* frequency analysis (e.g. Burn, 1990; Zrinji and Burn, 1994; 1996; Tasker et al., 1996). The present study focuses on development of the ROI approach to the frequency analysis of *precipitation* extremes; we evaluate a number of alternative settings and present a comparison with the 'standard' regional frequency analysis of Hosking and Wallis (1997). Our innovation to the ROI methodology consists in alternative ways of defining the between-site similarity: closeness of sites is not only determined according to the statistical properties of the at-site data, but also by means of long-term characteristics of precipitation climate and geographical proximity of stations.

DATA

Slovakia. Daily precipitation amounts measured at 56 stations operated by the Slovak Hydrometeorological Institute (SHMI) were used. Observations of daily precipitation amounts are available over the period 1961-2003 (in some cases since 1951). The basic data set at the selected 56 sites makes up 2464 station-years. The altitudes of stations range from 100 to 2635 m a.s.l.; the density of the selected sites is approximately one per 900 km^2.

Czech Republic. Daily precipitation totals measured at 211 stations operated by the Czech Hydrometeorological Institute (CHMI) were used as an input dataset. The observations span the period 1961-2005, the basic data set is comprised of 9274 station-years. The altitudes of stations range from 158 to 1322 m a.s.l.; the density of the sites is about one per 400 km^2.

The block maxima approach to the selection of extremes is adopted in the present study. Samples of maximum 5-day precipitation amounts in warm season (April to September) were drawn from each station record. The data underwent standard quality checking for gross errors as well as checking in terms of a discordancy measure based on L-moments (Hosking and Wallis, 1997).

DESCRIPTION OF THE REGION-OF-INFLUENCE METHOD

Distance metric

The region of influence for a given site consists of a group of sites that are sufficiently similar to the site of interest; the similarity of sites is judged according to site attributes. The Euclidean distance metric serves to determine the proximity of sites in the attribute space:

$$D_{ij} = \left[\sum_{m=1}^{M} \left(X_m^i - X_m^j \right)^2 \right]^{\frac{1}{2}}, \tag{1}$$

where D_{ij} is the Euclidean distance between sites *i* and *j*, X_m^i is the value of the *m*-th attribute at site *i*, and *M* is the number of attributes.

Site attributes

In the current study, 3 different alternatives to the selection of the site attributes are evaluated.

Alternative #1 (a1): site statistics. The whole set of the site attributes consists exclusively of statistical characteristics that are related to the examined data sample (seasonal maxima) at each site. The aim of this alternative is to pool sites with similar probability distributions of extremes. The following site statistics are considered:

a) coefficient of variation ($c_v = \sigma/\mu$, where μ (σ) is the sample mean (standard deviation));

b) Pearson's second skewness coefficient ($PS = 3(\mu - m)/\sigma$, where m is the median of the sample);

c) 10-year design precipitation estimated using the generalized extreme value (GEV) distribution.

Alternative #2 (a2): general climatological site characteristics. The set of the site attributes consists of characteristics that describe the long-term precipitation regime, regardless of the observed extremes. The basic idea of this alternative is that under similar climatological conditions, mechanisms generating heavy precipitation may also be similar. The following variables are considered:

a) mean annual precipitation;
b) mean ratio of the precipitation totals for the warm/cold season;
c) Lapin's index of the Mediterranean effect. Precipitation regime of Slovakia, mainly in autumn, is influenced by cyclones moving from the area of the Ligurian Sea. Due to this phenomenon, a secondary autumn maximum (in October or November) appears at majority of stations in South Slovakia. Lapin's index of the Mediterranean effect is a quantitative characteristics of the magnitude of this influence (more details in Gaál, 2005).

Since Lapin's index of the Mediterranean effect is defined exclusively for climatological conditions of Slovakia, it could not be used for the analysis in the Czech Republic. Instead of it, mean annual number of dry days (defined as days with precipitation amount ≤ 0.1 mm) was taken as the third climatological site characteristics for the Czech Republic.

Alternative #3 (a3): geographical site characteristics. The 3rd set of site attributes consists of basic geographical co-ordinates: a) latitude, b) longitude and c) elevation above sea level. This alternative has been chosen according to a hypothesis that geographical proximity of sites may also be an indicator of similar regimes of extreme precipitation.

Transfer of regional information

Two issues need to be addressed for a transfer of regional information: one need to determine how many sites to include into a given site's pooling group (choosing a threshold value for the matrix *D*), and what relative importance to assign to those sites (calculating weighting coefficients). Following Burn's (1990) framework, the threshold distance and the weights in the current analysis are determined according to 3 different options that reflect 3 diverse concepts of pooling information from the sites of the ROI: *Option #1 (o1): "Less sites with high values of weights"*. The ROI for a given site encompasses only a limited number of stations; however, all of the selected stations are assigned weighting parameters noticeably different from zero. *Option #2 (o2): "More sites with different values of weights"*. A relatively large number of sites are included in the ROI for a given site. Stations sufficiently similar to the site of interest have unit weights, while to those that are less similar, lower values of weights are assigned. *Option #3 (o3): "All sites with different values of weights"*. Option #3 is similar to option #2 with the only difference that all available stations are included in the ROI for a given site, with appropriate values of the weighting function. For a more detailed description of individual options (e.g. equations and parameter settings) refer to Burn (1990).

Estimation of growth curve quantiles

Growth curve quantiles at a given station are estimated according to the *regional L-moment algorithm* (Hosking and Wallis, 1997). The only difference is that regional (pooled) L-moment ratios $t_r^{(i)R}$, $r = 2, 3, \ldots$ within the ROI for site *i* (ROI_i), are derived using weights η_{ij} from options #1-#3:

$$t_r^{(i)R} = \sum_{j \in ROI_i} t_r^{(j)} n_j \eta_{ij} \Bigg/ \sum_{j \in ROI_i} n_j \eta_{ij}\,, \quad r = 2, 3, \ldots, \tag{2}$$

where η_{ij} is weight of site *j* within the pooling group of site *i*, n_j is the length of observations at site *j*, and $t_r^{(j)}$, $r = 2, 3, \ldots$ are the sample L-moments ratios at site *j*. The regionally weighted values $t_r^{(i)R}$, $r = 2, 3, \ldots$ are then used to estimate parameters of the selected distribution function in order to get the quantiles of dimensionless cumulative distribution function (growth curve).

A universal parametric model for extremes, the generalized extreme value (GEV) distribution (e.g. Coles, 2001), is applied as the pooled distribution function in the current analysis. It has been identified as a suitable model for 1-day as well multi-day precipitation extremes in central Europe, including the areas of Slovakia and the Czech Republic (Gaál, 2006; Kyselý and Picek, 2007).

Evaluation of the ROI approaches

In order to evaluate the performance of various ROI approaches (combinations of 3 'alternatives' and 3 'options'), Monte Carlo simulations are carried out. They consist of $NR = 1000$ repetitions. In each repetition, samples of annual maxima are generated at each station, having the same record lengths as their real-world counterparts. In simulation procedures, GEV is assumed as a parent distribution at each site. Simulated quantiles are calculated according to the above described sequence of the ROI methodology, and they are used together with the 'true' (parent) at-site quantiles to calculate summary characteristics describing the performance of a given model, i.e. the average *root mean square error* (*RMSE*) and average *bias* for a given return period *T*:

$$RMSE^T = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{1}{NR}\sum_{m=1}^{NR}\left(\frac{\hat{x}_{i,m}^T - x_i^T}{x_i^T}\right)^2\right]^{\frac{1}{2}} \tag{3}$$

and

$$BIAS^T = \frac{1}{N}\sum_{i=1}^{N}\frac{1}{NR}\sum_{m=1}^{NR}\left(\frac{\hat{x}_{i,m}^T - x_i^T}{x_i^T}\right), \tag{4}$$

where N is the number of analyzed sites, x_i^T is the 'true' (at-site) value for the T-year event at site i, and $\hat{x}_{i,m}^T$ is the simulated value of the T-year event at site i from the m-th sample of the Monte Carlo simulations.

The performance of 9 ROI models, labelled as *a1o1*, *a1o2*, *a1o3*, *a2o1*, ..., is compared with results of 2 other frequency models:

i) *HWreg* – "conventional" regionalization approach of Hosking and Wallis (1997), in which 3 homogeneous regions are delineated within Slovakia (Gaál, 2006) and 9 homogeneous regions within the Czech Republic (Kyselý and Picek, 2007);

ii) *HWnor* – the same as (i), but *HWnor* treats Slovakia (the Czech Republic) as a single region.

RESULTS

Slovakia. Tab. 1 gives an overview of the average values of *RMSE* for 6 relevant return periods *T*, while box plots in Fig. 1 (left) show a more detailed view on *RMSE* of quantiles corresponding to *T* = 100 years (similar patterns of box plots are observed for other return periods). Results of an intercomparison of 11 regional frequency models are summarized as follows:

1) The best alternative of the ROI approach is #1, i.e. when sites are pooled according to the statistical properties of the individual samples. It follows from Fig. 1, where three models *a1* have the narrowest boxes and whiskers. Average values of *RMSE* of the *a1* models in Tab. 1, however, contradict to this statement, since models *a1o1* and *a1o2* show the worst performance among the ROI models, the *a1o3* model is the best one overall, and the other 6 ROI models show a relatively balanced performance. Such behaviour of the ROI models may be explained by the way of pooling sites in the Monte Carlo simulations. In each simulation loop for alternative #1, composition of pooling groups and regional weighting factors are recalculated, as simulated at-site samples have different statistical properties each time. On the contrary, structures of pooling groups in alternative #2 (#3) are independent of the simulated at-site samples, since in each simulation loop, the same climatological (geographical) characteristics corresponding to the real situation are used.

2) According to Tab. 1, the best option seems to be #3; however, based on box plots in Fig. 1 (left), it is hard to make a clear distinction about the best way of the transfer of regional information.

3) All ROI models have small positive bias regardless of the return period, i.e. they slightly overestimate the real growth curve values (not shown). Nevertheless, the smallest bias, particularly for higher return periods ($T \geq 50$ years) is observed in case of the *a1o3* model.

4) Of the two Hosking-Wallis models of the regional frequency analysis, *HWreg* shows better performance than *HWnor*: even though *HWreg* has slightly higher averages (Tab. 1), it outperforms *HWnor* in terms of other characteristics (narrower box and whiskers, Fig. 1; a slightly better behaviour in terms of bias, not shown).

5) The most appropriate model of the regional/pooled frequency analysis in Slovakia is therefore the ROI approach *a1o3*.

Table 1. Average root mean square error ($RMSE^T$) of growth curves of maxima of 5-day precipitation amounts in warm season in Slovakia for return periods *T*. The smallest values for each *T* are in bold.

T[yrs]	*a1o1*	*a1o2*	*a1o3*	*a2o1*	*a2o2*	*a2o3*	*a3o1*	*a3o2*	*a3o3*	*HWre*	*HWno*
5	0.018	0.018	0.018	0.016	**0.015**	**0.015**	**0.015**	**0.015**	**0.015**	0.020	0.020
10	0.030	0.030	0.028	0.028	0.028	**0.027**	0.028	**0.027**	0.028	0.033	0.032
20	0.048	0.048	**0.045**	0.046	0.046	**0.045**	0.047	0.047	0.047	0.052	0.051
50	0.077	0.077	**0.070**	0.074	0.074	0.072	0.076	0.075	0.074	0.081	0.079
100	0.102	0.102	**0.092**	0.097	0.097	0.095	0.098	0.098	0.097	0.105	0.101
200	0.129	0.130	**0.114**	0.121	0.121	0.118	0.122	0.121	0.120	0.129	0.124

Table 2. Same as in Table 1 except for the Czech Republic.

T[yrs]	*a1o1*	*a1o2*	*a1o3*	*a2o1*	*a2o2*	*a2o3*	*a3o1*	*a3o2*	*a3o3*	*HWre*	*HWno*
5	0.018	0.018	**0.016**	0.017	0.017	0.017	0.017	0.017	0.017	**0.016**	0.017
10	0.030	0.029	**0.028**	0.031	0.031	0.031	0.030	0.031	0.031	**0.028**	0.032
20	0.056	0.052	0.050	0.054	0.055	0.055	0.054	0.056	0.056	**0.048**	0.058
50	0.099	0.092	0.084	0.092	0.092	0.093	0.091	0.095	0.094	**0.081**	0.098
100	0.136	0.126	0.112	0.122	0.123	0.124	0.122	0.126	0.126	**0.110**	0.131
200	0.177	0.164	0.141	0.154	0.155	0.156	0.154	0.159	0.158	**0.139**	0.165

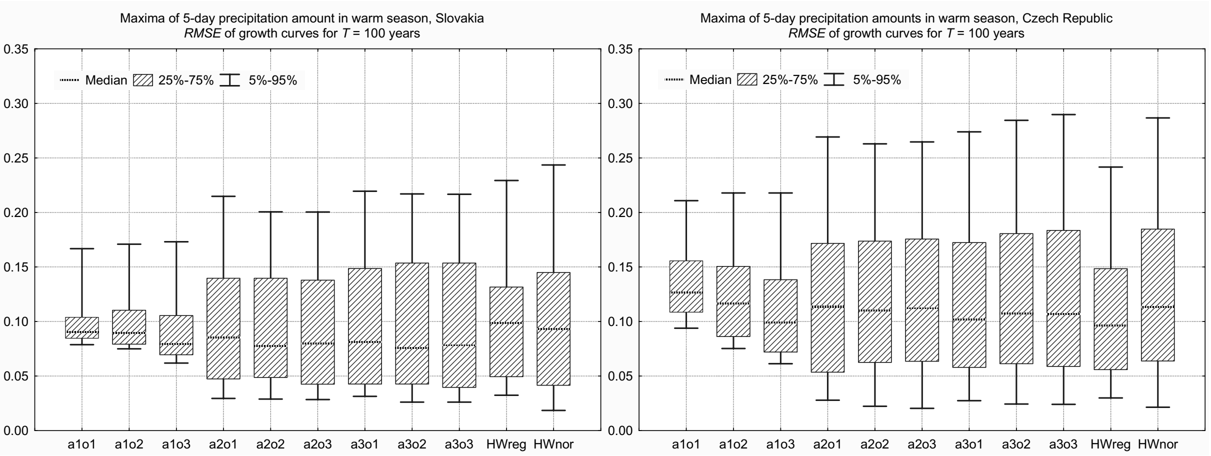

Figure 1. Root mean square error (*RMSE*) of growth curves of return period T = 100 years of 5-day precipitation amounts in warm season in Slovakia (left) and the Czech Republic (right).

Czech Republic. Tab. 2 summarizes average *RMSE* values for different frequency models, while box plots of *RMSE* of the 100-year quantiles are presented in Fig. 1 (right).

1) Conclusion 1) from the previous section about Slovakia holds true also for the Czech Republic.

2) Results (Tab. 2, Fig. 1 and other, not presented box plots) do not enable to pick out the best option for the transfer of regional information.

3) Both positive and negative bias appears in the ROI models (not shown). Underestimated quantiles are found particularly for higher return periods, and in case of the models based on alter-

natives #1 and #2, respectively. The most interesting fact is that the most favourable *RMSE* and the worst bias occur in case of model *a1o3*. Such an underestimation of quantiles may stem from considerable differences in spatial patterns of the shape parameter of the GEV distribution throughout the country (cf. Kyselý and Picek, 2007).

4) Of the two Hosking-Wallis models, *HWreg* that makes use of an elaborated subdivision of the country into 9 regions is obviously superior to the *HWnor* model.

5) There are two frequency models that stand out with their performance among the other ones: the ROI model *a1o3* and the HW model based on 9 regions *HWreg*. It is hard to choose which of these two models is the best one: *HWreg* shows slightly better performance in terms of average values of *RMSE* (Tab. 2) and bias (not shown); on the other hand, the *a1o3* model is favourable as to the spread characteristics presented in terms of box and whiskers plots of *RMSE* (Fig. 1, right) and bias (not shown), respectively. Further analyses are needed to find the best model.

DISCUSSION AND CONCLUSIONS

A variant of the ROI approach *a1o3* (in which the between-site similarity is determined according to statistical properties of at-site data samples, and regional information is pooled with appropriate weighting coefficients from all stations under study) outperforms the *HWreg* model (with 3 homogeneous regions) in Slovakia. This fact may stem from several contributing factors: i) a relatively small extent of the area; ii) a relatively high spatial homogeneity of the analyzed data set and iii) possibly not the most appropriate delineation of the country into subregions (contiguous geographical regions preferred in the process of the delineation; Gaál, 2006). Analogously, the balanced performance of frequency models ROI-*a1o3* and *HWreg* (with 9 subregions) in the Czech Republic may be observed due to i) bigger spatial extent of the country and a higher density of the sites; and ii) considerable regional heterogeneity of the analyzed data set. Note that the ROI analysis was conducted using the original parameter settings of different ROI options (Burn, 1990) in both countries. Such an approach may be beneficial in Slovakia, where the number of selected sites (56) is comparable to the number of sites in Burn’s analysis (45), but may not be applicable in such a straightforward way in the conditions of the Czech Republic, with 211 sites available. Therefore, further analyses have to be made in order to set the parameters of the ROI options correctly. The most essential question, whether the ROI approach outperforms the HW regional frequency analysis, cannot be answered at this time – further data sets (of durations from 1 to 7 days during different seasons) have to be analyzed to draw an unequivocal conclusion.

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Effect of climate change on the flow regime and snow conditions in a small agricultural study catchment

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ABSTRACT

The Integrated Nutrients Model for Catchments – Nitrogen (INCA-N) model was applied in Savijoki, a small (15.4 km^2) agricultural research catchment, in order to analyse the effect of the predicted climate change on the flow regime and snow conditions. The INCA-N model is a semi-distributed catchment model to simulate water flow and inorganic N leaching from terrestrial sources, and N transport and transformation processes in the soil and river. The main emphasis was on estimating changes in wintertime runoff and snow conditions as they are key variables for controlling agricultural nutrient losses in Finnish conditions. Firstly, long term runoff data (1981–2004) was used to analyse the possible link to the NAO index. The index was positively correlated to winter precipitation, runoff and mean temperature. Secondly, the hydrological part of the INCA-N model was calibrated for the period 1995–2004 and validated for the period 1985–1994. The calibrated model was then used to simulate the hydrological pattern in the new equilibrium climate (period 2071–2100) with four climate change scenarios. The selected scenarios predict 2.8–4.7 ºC increase in mean annual temperature and 10.1–23.6 % increase in annual precipitation, the changes being most prominent during winter. Annual runoff was predicted to increase 32 % on average in the scenario simulations, and the changes were highest during autumn and winter months. Accumulation of snow cover changed drastically: the snow cover disappeared on average one month earlier than at present and the maximum snow water equivalent decreased on average as much as 77 %. These major changes in the hydrological regime constitute a risk of considerably enhanced agricultural nitrogen leaching during the dormant season, and call for efficient mitigation methods and also a new strategy for water quality monitoring.

INTRODUCTION

Finland's climate is continuously changing and the changes may accelerate in the future. As summarized by Carter (2007) the projected climate of Finland warms and becomes wetter in all seasons and the changes are greater in winter than in summer. According to Tuomenvirta (2004), there has been a significant increase in the annual and spring (March-May) temperatures and from the 1970s onwards the increase has been rapid especially during wintertime. In future, the estimated responses of ecosystem services, being sensitive to climate, can be either beneficial (e.g. longer growing seasons) or harmful (e.g. endangered water quality as a result of enhanced nutrient leaching during winter) (Carter, 2007).

In Finland, the mean winter temperature is highly dependent on the NAO (North Atlantic Oscillation) index: during high index values, when south-westerly geostrophic winds dominate, the mean temperature is several degrees higher than during low index values, when south-easterly geostrophic winds are as common as south-westerly ones. Therefore, especially in southern and western Finland the snow water equivalent and snow depth are low if south-western winds dominate during winter (Solantie and Drebs, 2001).

Vagstad et al. (2004) analysed variations of observed nitrogen (N) losses from 35 Nordic and Baltic agricultural catchments. The results indicated that hydrological processes may have a marked effect on

N losses. According to Vuorenmaa et al. (2002), weather-driven fluctuation in discharge was usually the main reason for changes in nutrient losses from Finnish agricultural catchments. Previous Finnish studies, either based on water quality monitoring or modelling (Kallio et al., 1997; Puustinen et al., 2007) have shown that during mild winters nutrient fluxes from agricultural fields and catchments are higher than during "normal" winters. Moreover, profile scale climate change impact modelling predicted increase in agricultural N leaching as a result of enhanced mineralisation and increased water flow through the soil column (Kallio et al., 1997).

As a first step in predicting impacts of climate change on agricultural N leaching at small catchment scale, we used the INCA-N model (Whitehead et al., 1998; Wade et al., 2002) to calculate the runoff and snow water equivalent in the new equilibrium climate in south-western Finland, where intensive agricultural production is the major source N losses to surface waters. The effect of NAO on present climatic conditions is also discussed.

MATERIAL AND METHODS

The Integrated Nitrogen Model for Catchments, INCA-N, was applied in Savijoki, a small (15.4 km^2) agricultural study catchment in south-western Finland. The catchment belongs to the National monitoring network of small drainage basins, originally established for hydrological research in 1957 (e.g. Seuna 1983). There are no point sources in the catchments and monitoring results have been widely used to study processes related to nutrient leaching, and especially the impact of agriculture and forestry on water flow and quality (e.g. Vuorenmaa et al. 2002). As there are no lakes in the catchments and artificial drainage is widely used on the agricultural areas, the residence time is typically short. The proportion of fields is 39% for Savijoki and agricultural production, dominated by cereal cultivation, is the major source of diffuse nutrient losses (e.g. Vuorenmaa et al, 2002).

Mean annual and winter (December-March) precipitation, air temperature and runoff values from the period 1981–2004 were linked to the NAO index to describe the variability in present climatic conditions in Savijoki. The accumulation of snow cover was observed bi-weekly during winter along a snow course. Daily interpolated estimates were also available for areal snow water equivalent (SWE).

INCA-N is a process-based and semi-distributed model that integrates hydrology, catchment and river N processes to simulate daily concentrations of NO_3-N and NH_4-N in the river system. In this study, the most recent modified version 1.11.1 was used, with a simple degree-day model to calculate snow pack depth and a process based function to calculate soil temperature from ambient air temperature (Rankinen et al., 2004a, b).

In the INCA-N model, hydrologically effective rainfall (HER) is the input to the soil water storage driving water flow and N fluxes through the catchment system (Whitehead et al., 1998). Catchment hydrology is modelled with a simple three-box approach, including direct runoff and reservoirs of water in the reactive soil zone and deeper groundwater zone. Flows from the soil and groundwater zones are controlled by time constants, representing residence time in the reservoirs. INCA-N can simulate water flow and N processes in six land use classes. Base flow index (BFI) is used to calculate the proportion of water being transferred to the groundwater zone. Calculation of river flow is based on mass balance of flow and a multi-reach description of the river system. Flow variation within each reach is determined by a non-linear reservoir model (Whitehead et al., 1998).

The hydrological part of the INCA-N model has been earlier calibrated and validated in Savijoki for period 1981–2000 (Granlund et al., 2004). In this study, the calibration and validation was repeated with the most recent model version and new hydrological input data for period 1985–2004. The daily HER input data was derived from the Watershed Simulation and Forecast system WSFS. It is an operational system widely used in Finland for simulation of hydrological cycle and for real-time flood forecasting (Vehviläinen,1994; Vehviläinen & Huttunen, 2002). The study period was divided into two 10-year periods for indepent hydrological calibration and validation. The hydrological parametrisation of INCA-N was mostly similar to that in the earlier calibration. In addition to plotting the modelled versus observed values of runoff and SWE, the performance of the model was assessed by calculating the Nash and Sutcliffe (1970) coefficient for model efficiency.

The calibrated model was then used to simulate the hydrological pattern (runoff and snow conditions) in the new equilibrium climate (representing period 2071–2100) with four climate change scenarios developed within the PRUDENCE-EU project (Christensen et al., 2007). Monthly changes relative to control period 1961–1990 were simulated with the Regional Climate Model RCAO (Rossby Centre, SMHI, Sweden) (Döscher et al., 2002), driven by IPCC SRES forcing scenarios A2 and B2 of HadAM3 (Hadley Center, UK) and ECHAM4/OPYC3Y (Max-Planck Institute, Germany) Global Circulation Models. The selected scenarios suggest an annual increase of 2.8–4.7 ºC in temperature and 10.1–23.6 % increase in precipitation (Table 1). Monthly changes were added to observed daily temperature (ºC) and multiplied with daily precipitation (%).

Table 1. Temperature and precipitation changes in Savijoki for period 2071–2100 according to RCAO model (Döscher et al., 2002) and four different scenarios developed in the PRUDENCE-EU project (Christensen et al., 2007). DJF refers to period December-February etc.

	DJF	MAM	JJA	SON	Year
ΔT (ºC)					
RCAO-HA2	4.5	4.1	3.5	4.1	4.1
RCAO-HB2	3.4	3.0	1.8	3.0	2.8
RCAO-EA2	6.2	4.7	3.5	4.4	4.7
RCAO-EB2	4.8	3.8	2.6	3.4	3.7
ΔP (%)					
RCAO-HA2	39.6	1.4	-0.4	8.8	12.3
RCAO-HB2	25.6	-4.3	6.3	10.0	10.1
RCAO-EA2	55.7	33.0	-8.5	26.2	23.6
RCAO-EB2	44.6	21.6	-2.5	26.8	21.1

RESULTS

The year-to-year variation of SWE is high in Savijoki (Fig. 1). During winter months (December-March), the NAO index had a positive correlation with mean temperature, precipitation and runoff (Kendall's tau_b 0.533, 0.607 and 0.560 respectively) indicating a strong effect of westerly flows from the North Atlantic.

The capability of the INCA-N model to describe the present snow conditions was reasonable (Fig. 1). The modelled vs. observed discharge also showed a good agreement for daily values both for calibration and validation periods ($R^2 = 0.90$ and 0.88, respectively).

The remarkable increase in winter temperatures and precipitation (December-February, Table 1.) predicted by the different scenarios influenced strongly the hydrological regime in Savijoki: the modelled SWE remained below 20 mm and the snow cover period shortened approximately by one month in spring (Fig. 2a). The maximum SWE decreased by 77 % on average. Accordingly, the changes in the flow regime were significant: late autumn and winter runoff increased strongly, thus substituting the snowmelt runoff peak occurring typically in April in present climatic conditions (Fig. 2b).

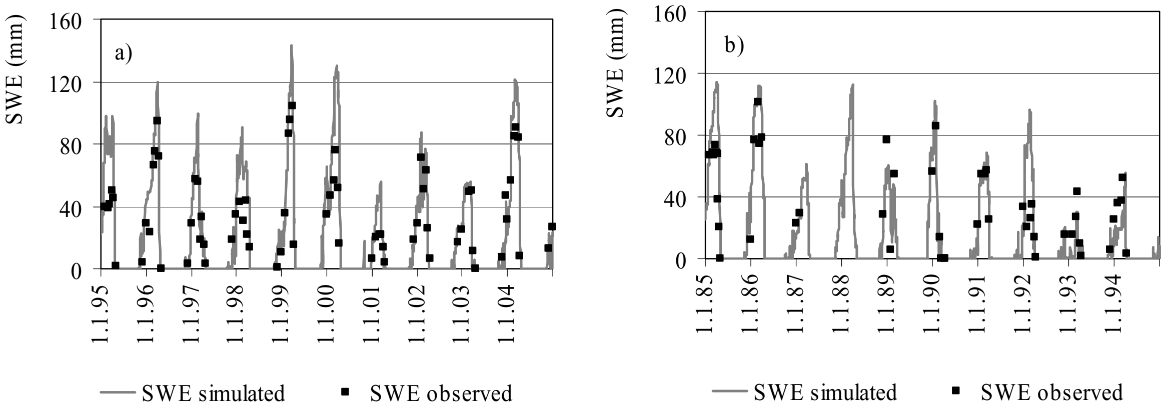

Figure 1. Observed and simulated snow water equivalent (SWE, snow course measurement) in Savijoki catchment during the INCA-N model calibration (a: 1995–2004) and validation (b: 1985–1994) periods.

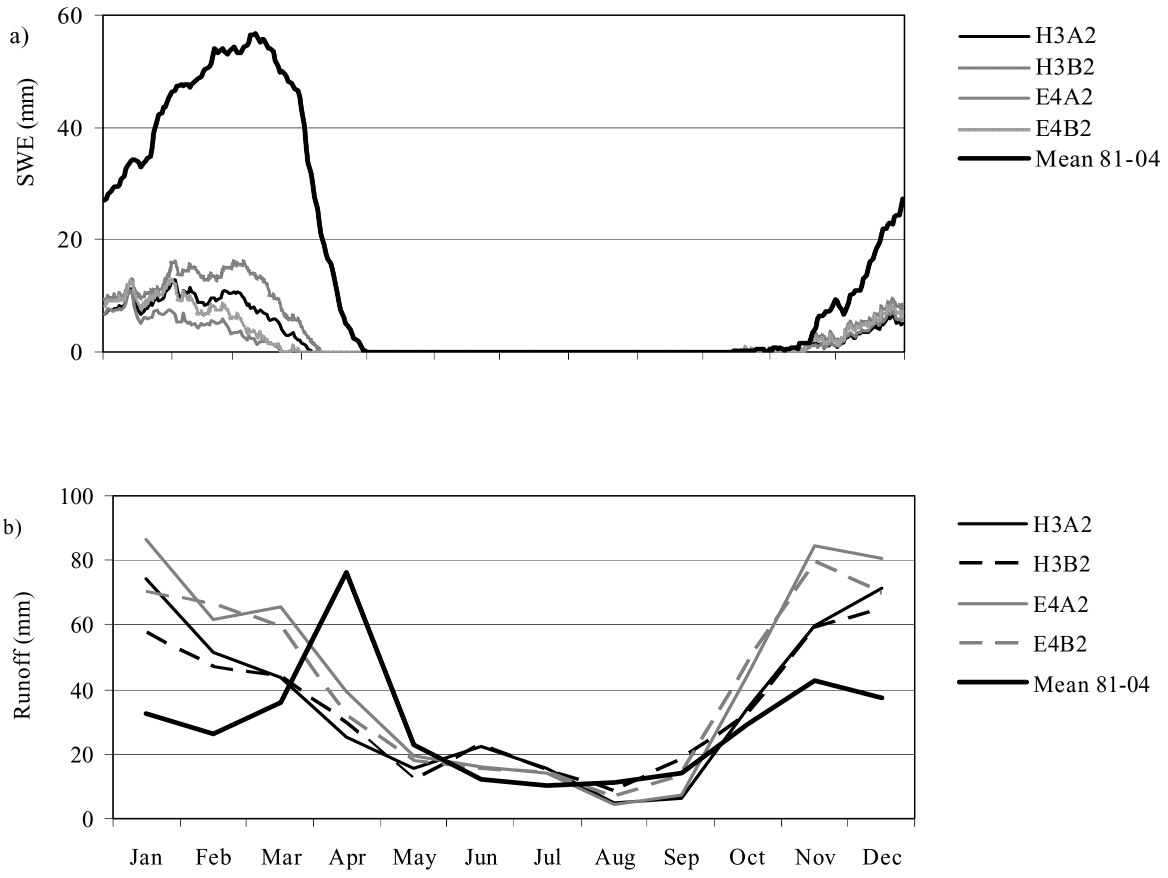

Figure 2. (a) Predicted (2071–2100) snow water equivalent with respect to average present snow water equivalent, and (b) predicted (2071–2100) monthly runoff with respect to average present values (period 1981–2004). H3A2 refers to RCAO -HA2 climate change scenarios in Table 1 etc.

DISCUSSION AND CONCLUSIONS

Climate change impact simulations at the Baltic Sea scale predict an increase of river flow from the northern part of the catchment (Graham, 2004). Similarly, it has been estimated that in Finland melting of snow - coupled with increased precipitation - could double the mean river discharge during winter by 2100. In southern Finland, the mean spring flood level may decrease significantly because of the decreased amount of snow (Silander et al., 2006). Our results on the overall hydrological response to climate change on the small catchment scale are in accordance with the above mentioned regional results.

Leaching of nitrogen and annual riverine nitrogen load is highly dependent on hydrometeorological conditions (e.g. Grimwall et al., 2000; Vagstad et al., 2004). The predicted major changes in snow accumulation and winter runoff in the Savijoki catchment pose a threat of considerably increased nitrogen leaching. The agricultural sector should be aware of this risk: winter time crop cover on fields would become especially important. Modelling of the hydrological and water quality impacts of climate change are needed at small scale catchments to provide insight into mitigation measures needed, for instance a change in flow regime would probably also effect the hydraulic design of constructed wetlands. The present water quality monitoring strategy is concentrated on high flow periods in spring and autumn. A new design of this strategy will be needed to provide reliable estimates for nutrient losses in research catchments. Many accumulating uncertainties are related to climate change studies starting from the deficiencies in the process descriptions of the different models used and ending with problems related to predicting adaptation of the agricultural sector not only to changed climatic conditions but also to changes in the common agricultural policy. The forthcoming new climate change studies in the Savijoki catchment attempt to take into account also the predicted changes in agricultural land use.

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Modeling of Evapotranspiration from Forested Watersheds Using HSPF

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Keywords: Climate Change, Evapotranspiration, Simulation, Trend, Watershed, HSPF

ABSTRACT

This study deals with the effects of the expected climate change on the hydrology of watersheds. The hydrological processes in the watershed have been modeled using HSPF (Hydrological Program FORTRAN). Climate change scenarios have been prepared based on trends expected in western Turkey and a forested hypothetical watershed been simulated. Comparisons with a base scenario which does not exhibit changes in climatic conditions have been conducted to see how different vegetation covers (a coniferous and a deciduous forest) will respond to trends in temperature and precipitation. It has been found out that monthly variations are important in predicting the future response of watersheds. Moreover the effects of a parameter which regulates evapotranspiration on the watershed outflow has been investigated.

INTRODUCTION

The hydrologic regime of watersheds are to a high degree determined by climatic conditions which prevail over the area and persisting changes in these conditions will lead to alterations in the regime. Temperature and precipitation, together with the other climatic variables are expected to change appreciably during the twenty-first century. Surface temperature increases of a few degrees are expected in the first half of the century and significant increases or decreases are projected for precipitation. Droughts and floods will likely increase in frequency, duration and strength (IPCC, 2007). It is therefore desirable to be able to estimate what awaits the society in the future with respect to the anticipated climate change and the associated changes in the watershed response. The forecasts also must be in quantitative terms to incorporate the possible effects of the climate change into the watershed management plans.

This study aims to better understand how the watershed response to changes in climatic forcing is likely to evolve through the period of change and how a possible change in watershed properties interferes with this evolution. An experimental watershed is created and climatic forcing due to a climate change scenario is realized. The response of the watershed is modeled using HSPF (Hydrologic Simulation Program-FORTRAN). Two different vegetation covers (a coniferous and a deciduous forest) are considered and the water output of the watershed together with the evapotranspiration is investigated. In creating the climate change scenario, a different approach has been adopted in place of the generally used downscaling method (Wilby and Dawson, 2001; IPCC-TGCIA, 1999).

THE WATERSHED AND THE CLIMATE SCENARIOS

An experimental watershed of 1000 km^2 area and at an elevation of 800 m above sea level has been used in the simulations. The land has an average slope of 0.1% with a drainage density of 100 m^{-1}. In order to investigate the hydrological response under different soil permeability conditions, two soil hydrologic groups have been used, namely Soil Hydrologic Group A and D. Group A has a low surface overflow potential and is a highly permeable soil while Group D represents a soil with a high surface overflow potential and consequently low infiltration. The vegetation covers examined are a coniferous forest and a deciduous forest with different evapotranspiration potentials. In each, the watershed has been assumed to be solely covered by that particular vegetation.

For the generation of the time series to be used in the simulations, temperature, precipitation, wind velocity, cloud cover, and relative humidity measurements from the Kütahya Meteorological Station in western Turkey (obtained from the State Meteorological Agency of Turkey) have been arranged as daily records of means or totals from 1975 to 2003. Then the series have been extended into the future. In the case of temperature, a series has been constructed for every month from 1975 to 2003 composed of adjacent daily values. Autocorrelation analysis has shown that there is serial correlation among adjacent daily mean temperatures which can be modeled as an AR(3) process. Then the models have been extended beyond 2003 till 2050 using the AR(3) equations. For precipitation, it has been assumed that the 1975-2003 series will repeat itself. So the series has been extended beyond 2003 as a process repeating itself every 29 years with a stochastic component added to it which does not change the statistical properties but generates small fluctuations in daily values without change in the temporal aggregates. These meteorological series constitute the base (no climate change) scenario.

The climate change scenario has been prepared by imposing trends on the time series of the base scenario. The climatic trends have been based on the SRES A2 scenario of the Intergovernmental Board on Climate Change (IPCC, 2004). This scenario assumes a heterogeneous world with local influences with a fast population increase and associated economical development. The results of a General Circulation Model that has been developed by the Canadian Climate Center (CCC, 2004) based on the A2 scenario have been utilized. Daily values for the relevant series have been extracted using the data covering a period between 2000 and 2050 from a grid cell centered at Western Turkey. Monthly aggregate values have been subjected to a nonparametric trend analysis using the Kendall trend test and the associated Kendall-Theil Slope Estimator (Hirsch et.al., 1982; Hirsch et.al., 1984). Trends expressed as yearly changes over the study period have then been imposed on the base scenario time series. The temperature trends have been added linearly on the daily values of the base scenario which has produced a gradual and linear increase in temperatures in the study period. For precipitation, the trends, as monthly deficits or surpluses, have been added to the base scenario. Thus a change in precipitation as either increase or decrease in monthly values has been obtained for the A2 scenario. Then this change has been reflected as a stochastic process into the daily values. The resulting climate change scenario predicts increases both in temperature and precipitation on a yearly basis but there are significant monthly variations. Temperature decreases in winter months and sharp precipitation reductions are encountered in summer months. Summary data for the temperature and precipitation time series are presented in Table 1.

Table 1. Yearly summary data for the meteorological time series used in the simulations

	Base Scenario			A2 Scenario		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
Temperature (°C)	8.7	10.3	11.1	9.1	11.1	12.5
Precipitation (mm)	350	554	935	363	574	926

HSPF used in the simulations is a modular program and the module used in this study is the PERLND (PERvious LaND) module which treats the land area to be modeled as a segment whose characteristics are represented by lumped parameters. PERLND can be used to model land areas which infiltrate a significant portion of the precipitation falling on it into the underlying soil segments (Bicknell et.al., 1993). Default parameters used for similar watersheds have been utilized in this study as a hypothetical watershed has been modeled instead of a real watershed. The most important parameter differentiating the Soil Hydrologic Groups from each other is the infiltration capacity, which is represented in HSPF as the INFILT parameter (Donigian et.al, 2000).

In HSPF some parameters can vary on a monthly basis as the processes they represent have a seasonal dependence. The interception capacity for coniferous forests is not seasonally dependent, however, for deciduous forests seasonally-varying values have been used based on literature values. LZETP is an important parameter which determines evapotranspiration. Literature values have been utilized for LZETP. It is LZETP which has been chosen as the parameter which will respond to changes in the climatic conditions. All other parameters are the same for both the base and A2 scenarios. There are studies on how the evapotranspiration will change due to changes in climatic conditions and carbon dioxide enrichment (Goyal, R.K., 2004; Triggs et.al, 2004; Huntington, 2003) for particular crops and forests. A rather arbitrary 10% increase in the value of the LZETP parameter has been chosen to represent the response of vegetation cover to increasing temperature. The watershed hydrology has been simulated for 47 years from 2004 to 2050 with a simulation increment of 24 hours. The years before the climate change effect have been included to establish initial values for a number of state variables like storages.

RESULTS AND DISCUSSION

Simulation results aggregated on a yearly basis have revealed that there are differences for the watershed outflow and evapotranspiration between the Soil Hydrologic Groups and vegetation cover. These differences are shown in Table 2 The values are averages of 47 consecutive yearly totals.

Table 2. Watershed Outflow (PERO) and Evapotranspiration (TAET) for the two scenarios

Coniferous Forest	Hydrological Soil Group A	A2 Scenario	PERO, mm	86
			TAET, mm	499
		Base Scenario	PERO, mm	83
			TAET, mm	483
		% Difference	PERO, %	6.6
			TAET, %	3.5
	Hydrological Soil Group D	A2 Scenario	PERO, mm	69
			TAET, mm	515
		Base Scenario	PERO, mm	67
			TAET, mm	499
		% Difference	PERO, %	4.8
			TAET, %	3.5
Deciduous Forest	Hydrological Soil Group A	A2 Scenario	PERO, mm	127
			TAET, mm	458
		Base Scenario	PERO, mm	123
			TAET, mm	444
		% Difference	PERO, %	6.2
			TAET, %	3.1
	Hydrological Soil Group D	A2 Scenario	PERO, mm	99
			TAET, mm	486
		Base Scenario	PERO, mm	96
			TAET, mm	471
		% Difference	PERO, %	4.1
			TAET, %	3.3

The first difference is that the deciduous forest transpires less because the trees shed leaves in winter. Moreover the more permeable soil (Hydrological Soil Group A) produces more outflow. Because the A2 scenario predicts more precipitation, the outflow and evapotranspiration values for the climate change scenario are higher than the corresponding base scenario ones due to the presence of more water in the hydrological cycle. Figure 1 shows how the outflows and evapotranspiration volumes differ from the base scenario for a permeable soil. As evident from the plots, the A2 scenario deviates more and more from the base scenario as time progresses.

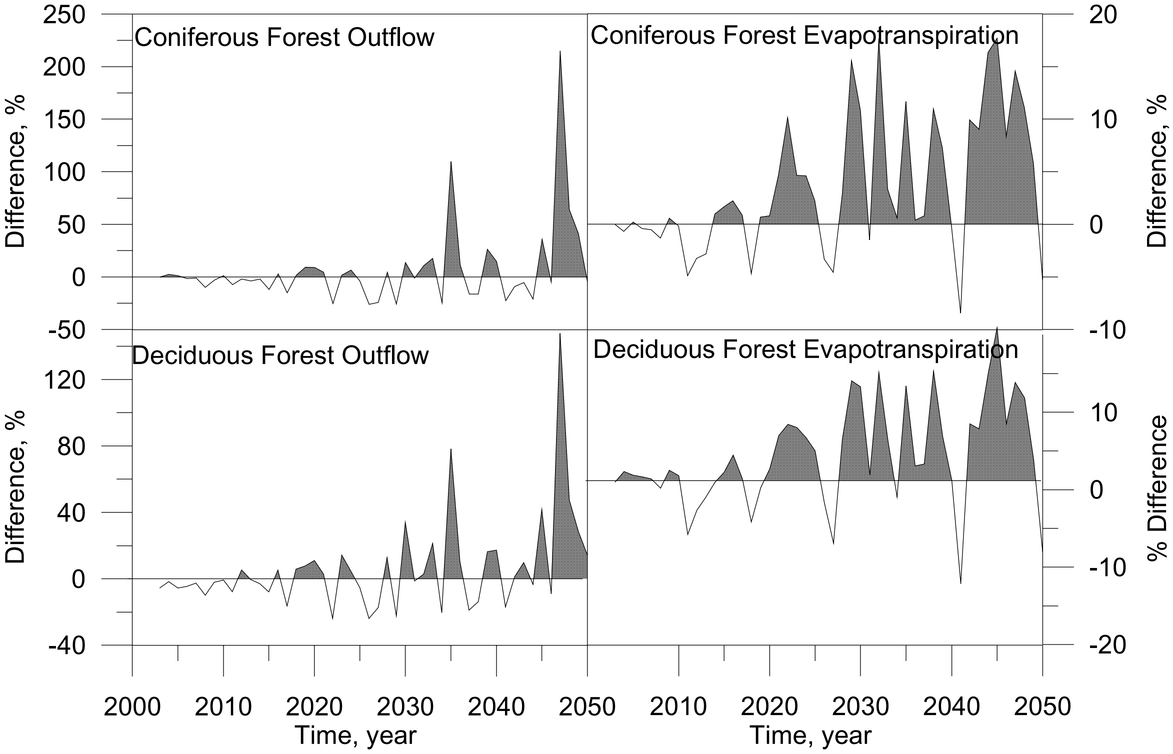

Figure 1. Deviation of the watershed outflows and evapotranspiration volumes of the A2 scenario from the base scenario for a Group A soil as percent differences

The changes are, however, not homogeneous on a seasonal basis. There are significant decreases in both outflow and evapotranspiration in the early summer months due to low precipitation and lowered soil moisture levels and high temperatures towards the end of the simulation period. Thus, while the overall effect of the climate change for this particular scenario is of increasing outflows, there are also drought periods of longer duration and intensity as compared to the base scenario.

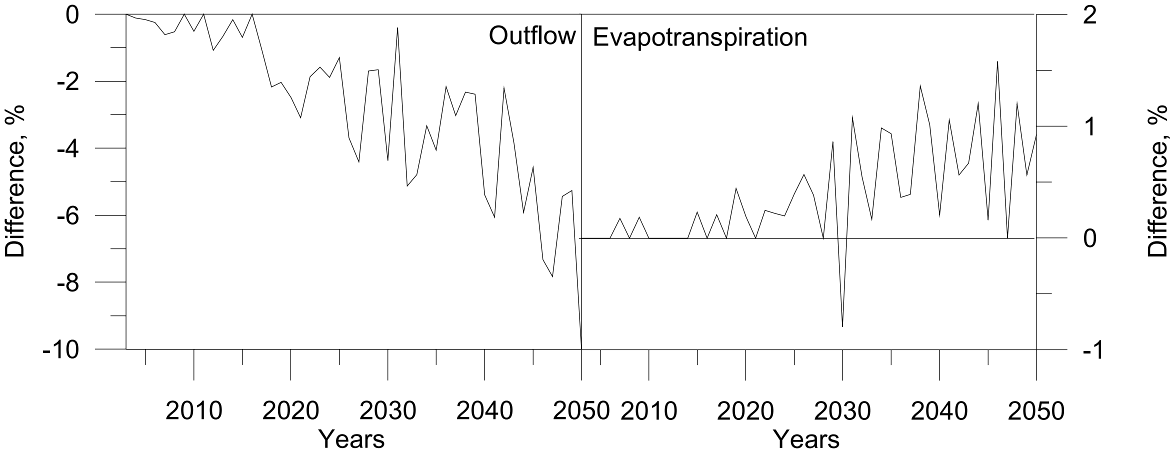

Figure 2. Difference in outflow and evapotranspiration for a coniferous forest on a permeable soil when LZETP is increased by 10% (A2 scenario)

When the LZETP parameter which controls lower zone evapotranspiration in HSPF is increased by 10%, decreases in outflows and increases in evapotranspiration volumes are observed on a yearly basis. This trend is clearly visible in Figure 2. While evapotranspiration increases are observed on a yearly basis, there are again seasonal differences. There are months with decreases in evapotranspiration with increases in LZETP both in winter and in summer. In July, evapotranspiration decreases together with outflow towards the end of the simulation period. This behavior can be explained with the fact that the soil moisture storage decreases with time due to elevated evapotranspiration in the first years of the simulation period. LZETP in these experiments have been increased linearly during the simulation towards its projected value (10% above the standard value). Figure 3 shows this behavior for a coniferous and a deciduous forest with a permeable soil for the month of July.

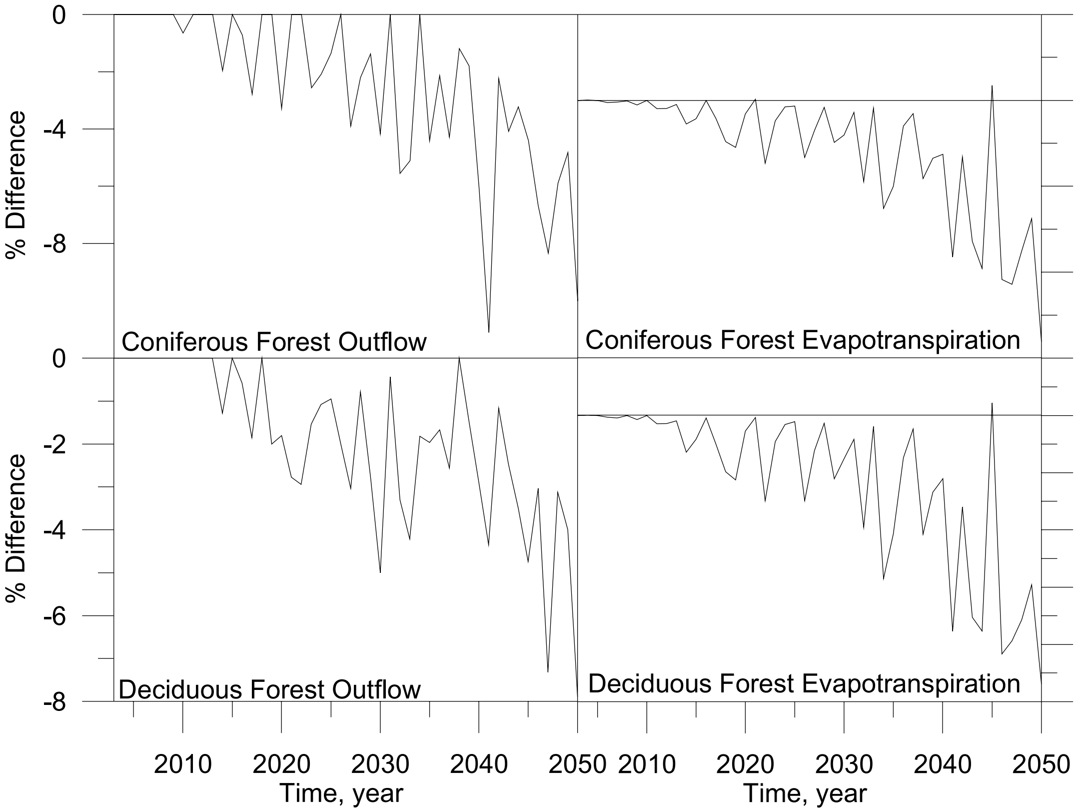

Figure 3. Difference in outflow and evapotranspiration for a coniferous and a deciduous forest on a permeable soil when LZETP is increased by 10% (A2 scenario) for the month of July.

CONCLUSIONS

HSPF can be used to estimate future trends of watershed hydrological response due to climate change based on estimates of climatic forcing. The fine temporal resolution allows rendering seasonal differences which can be very important as the meteorological forcing is itself seasonally varying and trends due to different factors may reinforce or dampen their effects seasonally. Parameters can also be changed during simulation reflecting the effects of climate change on the properties of the watershed. In this study, watershed outflow and evapotranspiration trends due to climate change have investigated. The outcome of a theoretical parameter perturbation (change in LZETP to reflect change in evapotranspiration due to increasing temperatures) has also been demonstrated. It can be said that seasonal differences are very important and that they get lost when the temporal resolution of the models used is not fine enough. In this respect HSPF is an effective modeling tool though data requirements are high.

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Conflicts between the reservoir water demand and climate changed inflow in case of different slovak water reservoirs

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Key words: Rainfall-runoff Monthly Balance Model, Water Reservoirs Orava and Vihorlat, Climate Change Scenarios, Water Demand.

ABSTRACT

Climate gradually changes owing to increased greenhouse effect. Many processes in landscape and many spheres of our life can be influenced by changed climate conditions. In this contribution the water reservoir ability to assure required water demand under changed climate conditions was studied.
The rainfall-runoff balance model WBMOD, which works in monthly time step, was used to express the expected changes of the water reservoir inflow and the required reservoir capacity at different climate conditions. Failures in the required water supply in volume and time for changed climate conditions were evaluated.

Time series of precipitation, air temperature and the observed reservoir inflows and outflows of each water reservoir were used as the model input data. Precipitation and air temperature were modified in each month according to the climate scenarios, which were calculated by models CCCM2000 and GISS1998 by Slovak climatologists and estimated for the catchments of water reservoir (WR) Orava and Vihorlat, for time horizons 2030 and 2075.

In relation to the changed climate conditions, one would expect some conflicts between the reservoir water demand and changed inflow, and then a rather significant change in water management of different water reservoirs. In the particular case of the Vihorlat reservoir, it can be concluded, that the expected climate change would influence the certainty of the real water supply from the reservoir only to a small extent. In addition, for the particular case of the Vihorlat reservoir, the results indicate also risks for the operators to provide the required water supply, on the score of partial reduction of the reservoir operational storage needed for the recreation purpose in the summer season. In the case of the Orava reservoir, expected climate change would considerably influence the certainty of the required water supply.

The climate change impacts as presented, are not the exact forecasts, because of uncertainties of the General Circulation Models (GCMs), as well as of the rainfall – runoff models outputs.

CLIMATE SCENARIOS FOR THE ORAVA AND LABOREC RIVER BASINS

The effect of climate change on hydrological processes varies regionally and between climate scenarios, largely following projected changes in precipitation. Demand for water is generally increasing due to population growth and economic development, but is falling in some countries because of increased efficiency of use. Climate change is unlikely to have a big effect on water demands in general, but may substantially affect irrigation withdrawals, which depend on how increase of evaporation is offset or exaggerated by changes of precipitation. Higher temperatures, hence higher crop evaporative demand, mean that the general tendency would be towards an increase in irrigation demands. Water resource management techniques can be applied to adapt to hydrologic effects of climate change, so as to lessen vulnerabilities (IPCC, 2001). Utilization of climate models is the most physically plausible method for preparation of regional climate change scenarios (Lapin and Melo, 2004). In this contribution data from two coupled general circulation models of two world climate centres: CCCM2000 (with IPCC"IS92a" forcing scenario) and GISS1998 were utilised. CCCM2000 is the second generation coupled global climate model of the Canadian Centre for Climate Modelling and Analysis in Victoria, B.C., (Flato and Boer, 2001). GISS1998 is the coupled atmosphere-ocean model from the Goddard Institute for Space Studies in New York, (Russell and Rind, 1999).

METHOD

Present horizontal resolution of GCMs does not allow making out some regional climate features. In this contribution a statistical method for downscaling of GCMs outputs was used. Statistical downscaling consists from development of statistical relationships between locally observed climate variables and outputs of global GCM experiments. Model outputs from gridpoints near to Slovakia were taken into account. Interpolation from these gridpoints to the considered locality (the weights with respect to the distance from concrete locality) was used. These calculations for time horizon 1971–1997 (WR Vihorlat), for time horizon 1951–1980 (WR Orava) and for next time horizons 2030 (2016–2045) and 2075 (2061–2090) were studied. Climatologists had elaborated the scenarios of air temperature change and precipitation change between these periods in form of either differences (air temperature) or quotients (precipitation). They used mean monthly values of both climatic elements. Climate scenarios in case of air temperature for meteorological stations and in case of precipitation for meteorological stations near the WRs Vihorlat and Orava had been prepared, (Halmova and Melo, 2006).

In the case of water reservoir Vihorlat the results achieved by both climate models are different, mainly in case of precipitation. In the 21st century we can await the increase of air temperature during all the year round according to both climate models. More expressive air temperature increase for eastern Slovakia in this century is projected by CCCM2000. In the first studied period (2016–2045) this increase is about 0.9°C (GISS), respectively about 2.0°C (CCCM) and in the next period (2061–2090) is increase about 2.3°C (GISS), respectively about 3.6°C (CCCM), in comparison with contemporary state (1971–1997 period). Changes of precipitation and air temperature according to the latest climate scenarios and estimated for the Orava reservoir catchment, for two time horizons 2030 and 2075 are in Table 1, Table 2.

Table 1. Climate scenario GISS1998 for catchment of water reservoir Orava (WR Orava), changes of mean monthly temperature in (ºC) and monthly precipitation totals (coefficient) according to scenario GISS1998

Air temperature	**(ºC)**	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
GISS1998	**2030**	1.24	0.97	0.75	0.85	0.88	0.81	0.82	0.73	0.66	0.94	1.20	1.25
	2075	2.66	2.39	2.32	2.22	1.91	1.80	2.08	2.31	2.24	2.32	2.64	2.81
Precipitaion	**(coeff.)**	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
GISS1998	**2030**	1.00	1.06	1.05	1.08	1.07	1.08	1.00	1.03	1.17	1.07	1.05	1.01
	2075	1.28	1.21	1.14	1.12	1.15	1.00	1.02	1.04	1.05	1.15	1.09	1.14

Table 2. Climate scenario CCCM2000 for catchment of water reservoir Orava (WR Orava), changes of mean monthly temperature in (ºC) and monthly precipitation totals (coefficient) according to scenario CCCM2000

Air temperature	**(ºC)**	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
CCCM2000	**2030**	1.90	2.31	2.88	2.83	2.06	1.88	1.90	1.81	1.71	1.35	1.15	1.44
	2075	3.77	4.59	4.73	3.89	2.87	3.00	3.31	2.26	3.28	3.04	2.71	2.91
Precipitation	**(coeff.)**	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
CCCM2000	**2030**	1.00	1.09	1.00	1.01	0.96	0.97	0.80	0.81	0.95	1.09	1.14	0.93
	2075	1.07	1.18	1.17	0.94	1.00	1.05	0.80	0.83	1.02	1.15	1.21	1.07

WATER BALANCE MODEL WBMOD WITH MONTHLY TIME STEP

Water balance models with monthly time step would be appropriate tools for the solution of projects dealing with the water supply. The calibration of these models is easier as well as accessibility of the input data. The monthly hydrological forecasting would be used for the real time operation, for irrigation or energy generation, Xu and Vandewiele (1995), (Gleick, 1986; Schaake and Liu, 1989; Arnell, 1992), (Nacházel *et al.*, 1995).
The WBMOD model is based on water balance model that was developed at V.U.B.–Vrije Universiteit Brussel-Hydrologie and basic equations and scheme of the model were described in several papers (Xu, 2000). The applied calculation technique "RESERVOIR" was developed by Halmova (2005).

METHOD

WR Vihorlat is located in the East Slovakia Lowland (ESL), the plain part of eastern Slovakia and it has above 2000 km^2. Total storage capacity of the reservoir is 334 mil.m^3, flood control storage is 100 mil.m^3, useful storage is 177 mil.m^3 and permanent storage is 57 mil.m^3. WR Orava is located in the north of Slovakia. Total volume of the reservoir is V_c=346.0 mil.m^3, permanent volume is V_s=27.3 mil.m^3, retention V_r from September to May is 20.5, from June to August is 40.6 mil.m^3 and than storage V_z is 298.1 or 278.0 mil.m^3.

Input data for the model WBMOD are average discharge in water level gauging station, monthly precipitation totals in raingauge stations and monthly average temperatures in temperature gauging station for the period 1971–1997 (WR Vihorlat) and for the period 1951–1980 (WR Orava). The operational rules of the reservoir indicate considerable variability of the outflow from water reservoir. It was the reason why ensuring this real outflow (period 1971–1997 and 1951–1980) from reservoirs in changed climate conditions was tested.

Monthly outflow series from the both water reservoirs during reservoir operation were calculated. Series of changed river inflow (according to climate scenarios CCCM2000 and GISS1998) as well as alternative changes of minimum operational reservoir water level were compared with this real chronological series, which represents a historical target. Changes of individual alternatives compared with the mentioned target are expressed by time series of the not supplied water volume during the failures in the demanded water supply, time series of the failures (period with lower water supply than required), total dependability of the supplied water volume in mm, total dependability of duration with no-failure operation in days. Changes of individual alternatives compared with the mentioned target were expressed by:

- time series of the not supplied water volume during the failures in the demanded water supply,
- time series of the failures (duration of a period with lower water supply than required),
- total dependability of the supplied water volume in mm,
- total dependability of duration with no-failure operation in days.

RESULTS

The reservoir inflow changes of both water reservoirs are introduced in two runoff scenarios for two time horizons 2030 and 2075. Outputs from model WBMOD are denoted as C/G1X and C/G2X (C/G – CCCM2000/GISS1998; 1–time horizon 2030; 2–time horizon 2075; X–alternative of model run). Several alternatives of model runs (A–E, M) were executed, for several initial conditions of the reservoir water levels. Only that water storage was used located between the minimum and maximum operating water level in both reservoirs. Initial and boundary conditions for WR Vihorlat (Table 3) are quantified in mil.m^3 above minimum operating level and above dead storage capacity. Initial and boundary conditions are *STMA* – maximal operating storage in water reservoir*, STMIL* – minimal accepted operating storage during summer months V.–IX., *STMIZ* - minimal accepted operating storage during winter months X.–IV., *SVZPO* – initial water storage in water reservoir at the beginning of each model run. Finally, total required water supply volume and total failures in water supply volume (in mm); total time period and time period with non-ensured water supply (in days) of simulation for individual alternatives were also quantified for both water reservoirs.

Table 3. Initial and boundary conditions of water reservoir Vihorlat.

Alternative Scenarios	Operation water level at STMIL storage (m a.s.l.)	STMA (mil.m^3)	STMIL (mil.m^3)	STMIZ (mil.m^3)	SVZPO (mil.m^3)
C/G-M1	107.39	177.0	0	0	0
C/G-M2	107.39	177.0	0	0	0
C/G-1A	113.9	177.0	177.0	40.4	40.4
C/G-1B	113.0	177.0	149.1	39.7	39.7
C/G-1C	111.0	177.0	92.7	39.7	39.7
C/G-1D	109.0	177.0	39.7	39.7	39.7
C/G-1E	108.0	177.0	14.6	14.6	14.6
C/G-2A	113.9	177.0	177.0	40.4	40.4
C/G-2B	113.0	177.0	149.1	39.7	39.7
C/G-2C	111.0	177.0	92.7	39.7	39.7
C/G-2D	109.0	177.0	39.7	39.7	39.7
C/G-2E	108.0	177.0	14.6	14.6	14.6

Calculated dependability of reservoir ability to secure a given water supply (= real water withdrawal from reservoir in volume (water storage) (ZZS) and in duration of non-failure operation (ZZT) for particular alternatives is listed in Table 4. These alternatives differ in minimum allowed summer water level (STMIL). Minimum summer water level limit can be connected with higher risk in supply of given water volume.

Table 4. Dependability of the given water supply in volume (ZZS) and in duration of non-failure operation (ZZT) for time horizon 2030 and 2075 and scenarios CCCM2000 and GISS1998, WR Vihorlat (a) and WR Orava (b)

(a)

time	*horizon*	*2030*	*time*	*horizon*	*2075*
Alternative scenarios	***ZZS***	***ZZT***	***Alternative scenarios***	***ZZS***	***ZZT***
CCCM-1M	0.982	0.963	CCCM-2M	0.975	0.960
CCCM-1A	0.798	0.764	CCCM-2A	0.794	0.761
CCCM-1B	0.879	0.851	CCCM-2B	0.873	0.851
CCCM-1C	0.962	0.966	CCCM-2C	0.957	0.950
CCCM-1D	0.971	0.957	CCCM-2D	0.966	0.957
CCCM-1E	0.978	0.960	CCCM-2E	0.972	0.957
GISS-1M	0.996	0.994	GISS-2M	0.996	0.991
GISS-1A	0.873	0.854	GISS-2A	0.856	0.835
GISS-1B	0.938	0.941	GISS-2B	0.927	0.935
GISS-1C	0.983	0.991	GISS-2C	0.981	0.988
GISS-1D	0.987	0.988	GISS-2D	0.985	0.984
GISS-1E	0.992	0.991	GISS-2E	0.993	0.991

(b)

time	*horizon*	*2030*	*time*	*horizon*	*2075*
Alternative scenario	***ZZS***	***ZZT***	***Alternative scenario***	***ZZS***	***ZZT***
CCCM─1M	0.883	0.870	CCCM─2M	0.815	0.793
CCCM─1A	0.780	0.782	CCCM─2A	0.730	0.729
CCCM─1B	0.816	0.804	CCCM─2B	0.766	0.789

CCCM—1C	0.838	0.829	CCCM—2C	0.790	0.798
GISS—1M	0.988	0.986	GISS—2M	0.956	0.943
GISS—1A	0.889	0.869	GISS—2A	0.841	0.821
GISS—1B	0.919	0.913	GISS—2B	0.877	0.864
GISS—1C	0.944	0.931	GISS—2E	0.903	0.884

RESULTS AND CONCLUSIONS

Presented conclusions, which result from WBMOD simulations, indicate potential possibilities of model utilization for reservoir operations, for particular reservoir utilisation for recreation, for analysis and development of models for seasonal runoff forecasts. This conclusion, of course, pertains only for the same water supply that had been realised during period 1971–1997 (WR Vihorlat) or 1951–1980 (WR Orava). However, in relation to the changed climatic conditions, one would expect a rather significant change in water management. The developed tool can be used for alternative hypothetical reservoir operation runs with various variants of the water supply regime defined as a time series, and also for case studies for other similar water reservoirs.

It can be concluded, that in this particular case of the Vihorlat reservoir the expected climatic change scenarios would influence the dependability of the water supply from the reservoir only to a minimum extent. Calculated dependability of reservoir ability to secure a given water supply (= real water withdrawal from reservoir during 1971—1997) in volume (water storage) (ZZS) and in duration of non-failure operation (ZZT) for particular alternatives is listed in Table 4a. These alternatives (C/G1A–E, C/G2A–E) differ in minimum allowed summer water level (STMIL), regarding to recreational purpose of Vihorlat reservoir. Minimum summer water level limit can be connected with higher risk in supply of given water volume. From the relationship between dependability of the water supply and minimum summer operating water level it is obvious that till summer water level wouldn't rise above the water level 111.0 m a.s.l., dependability of the water supply from reservoir wouldn't be considerably reduced. Even in the case of the minimum water level limit in summer operating level 113.94 m a.s.l., dependability of the water supply during 27 years would be approximately 80%, during some summer seasons would be higher.

Calculated dependability of WR Orava ability to secure a given water supply (= real water withdrawal from reservoir during 1951—1980) in volume (water storage) and in duration of non-failure operation for particular alternatives is listed in Table 4b. These alternatives (C/G1A–C, C/G2A–C) differ in minimum allowed summer water level (STMIL). Minimum summer water level limit can be connected with higher risk in supply of given water volume. In the case of climate scenario GISS1998 and time horizon 2030 dependability of given water supply in volume (water storage) and in duration of non-failure operation reach 99–95%. For time horizon 2075 dependability of the water supply during 30 years would be approximately 93%. In the case of climate scenario CCCM2000 dependability reach approximately 85% (for time horizon 2030) and 80% (for time horizon 2075). From the results of total required water supply volume (mm), total failures in water supply volume (mm), total time period (days) and time period with non-ensured water supply (days) during 30-years of simulation for individual alternatives it is obvious, that according to climate scenario CCCM2000 total failures in water supply volume and time period with non-ensured water supply are markedly higher than according to climate scenario GISS1998.

Differences between the results of storage deficiency according to different climate scenarios are evident for both water reservoirs. According to climate scenario CCCM2000 storage deficiencies are higher than according to climate scenario GISS1998.

The climate change impacts as presented, are not the exact forecasts. There are still uncertainties of the General Circulation Models (GCMs), as well as of the rainfall – runoff models outputs. Progress in modelling techniques for both is permanent and fast. So the research in climatology, hydrology and water resources management should be a continuous task also for future years and decades.

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Flood risk mapping – opportunities for better flood hazard management

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ABSTRACT

We present two pilot cases of flood risk mapping on two different spatial scales, based on a GIS analysis of several databases. An approach has been developed, which allows a combination of a simple flood hazard map (containing inundation area and water depths) with various spatial databases. Our first case study is from the settlement of Kittilä in Lapland. The economic hazard function has been solved based on a previous flood event in Kittilä in 2005, and the subsequent flood damage compensation payments. This flood event was well documented by both airborne photographs during the peak discharges and building-specific estimates of damages. Our second case area is the city of Pori at the mouth of river Kokemäenjoki in SW Finland. A detailed flood risk map gives a comprehensive picture of the damages, as it also shows a semi-quantitative estimate of economic damages involved in a flood event. We tested residential building flood damage function in Pori region and used a coarse value of 150€/m² as the average economic indicator of flood damage. This value corresponds to the best-fit straight line of data from Kittilä settlement damage for a 100 square meter residence. Cumulative monetary losses from individual residential buildings reached an estimate of 70 M€. This number parallels with the earlier study (Koskinen 2006) where the damages for both the residential and leisure buildings were estimated to climb to 77M € in HQ 250 flood event in the city of Pori.

INTRODUCTION

Flood risk maps offer a useful tool for societies in hazard mitigation. They serve various stakeholders in different spatial and temporal scales, from land use planners to rescue services. In the long run, the risk of damage, i.e. potential hazard, caused by flood water is an indication of how large investments in flood protection are economically viable in a specific case. In other words, it is not feasible to spend large sums of money to prevent moderate damages.

Based on an earlier survey, there are more than 60 flood-prone areas in Finland (figure 1) (Timonen et al. 2003). Damages of a severe widespread flood with 250 years' recurrence time could reach 550 million euros (Ollila et al. 2000).These two national reports estimate potential flood damages in Finland and give recommendations for minimizing them. In order to manage flood hazards and risks it is necessary to specify the amount of potential flood damage. Detailed delineation of potential flood risk areas and estimates of potential damages offer invaluable aid in better preparedness for the future floods. Flood hazard maps and flood risk maps form the most important toolkit in this process. Flood hazard map illustrates the inundation area and water depth for floods of specific return periods (Sane et al. 2005). General guidelines for flood hazard mapping in Finland were designed in the EXTRE-FLOOD project (2003–2005) coordinated by the Department of Geography in the University of Turku. This mapping exercise offered a starting point for the ongoing development of flood risk mapping. Flood risk map should be able to combine flood hazard with a degree of vulnerability, for example population or infrastructure.

An important driving factor in the development of flood risk mapping process in the EU is the Flood Directive currently under final preparation (EC 12331/6/06). The directive aims at giving common guidelines for future flood risk mapping procedures. A preliminary flood risk assessment should be completed by 2011 and the actual flood hazard and flood risk maps by the end of 2013 (European Commission 2006).

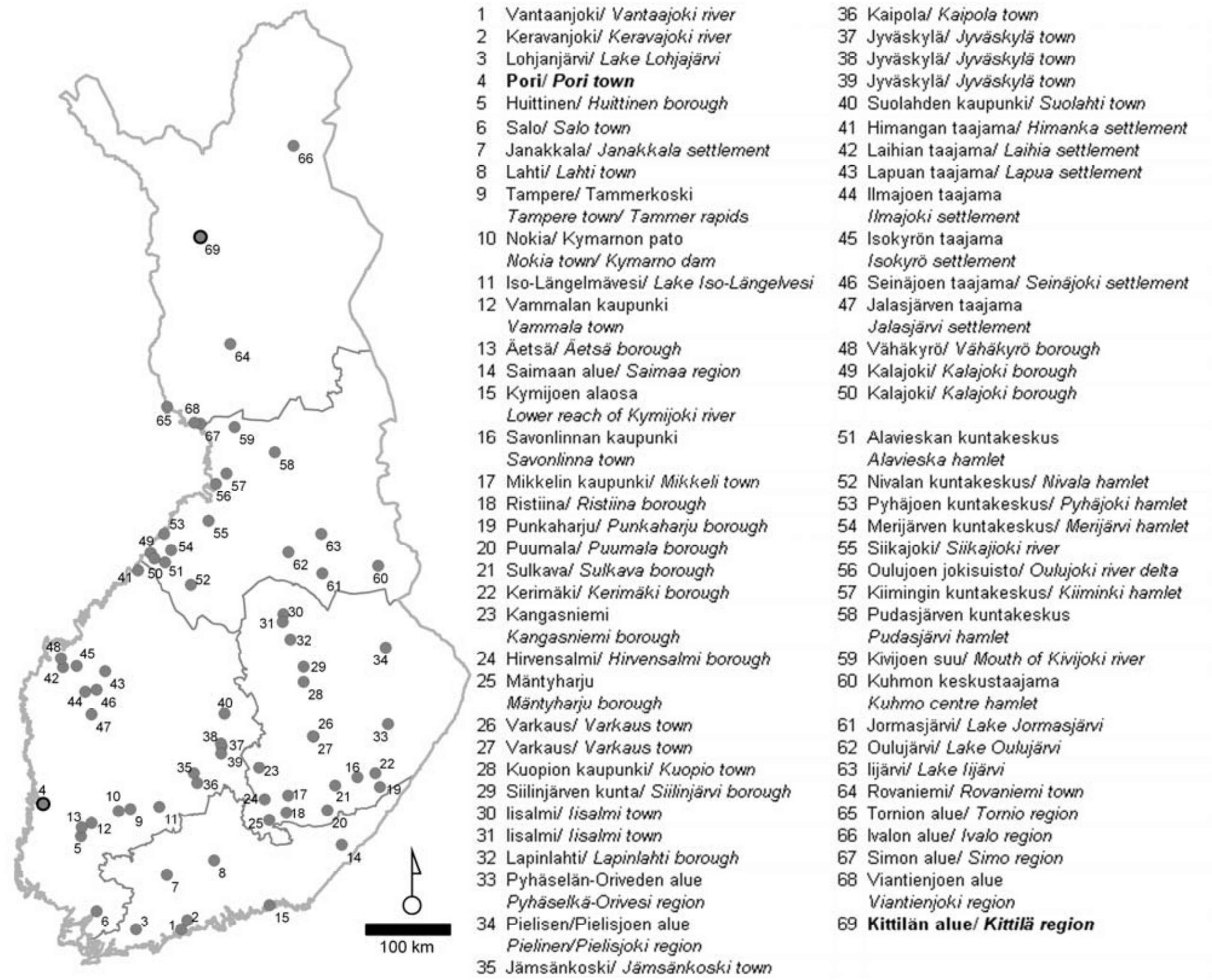

Figure 1. Major flood risk sites in Finland after Timonen et al. (2003).

Flood mapping practices for EU countries have been developed and evaluated in a project European exchange circle on flood mapping (EXCIMAP). The main objective of this project was to produce general guidelines for good practices in flood mapping in Europe, to be published in summer 2007. Examples of national flood maps from 17 EU countries are presented and compared in the publication "Atlas on flood maps in Europe" (Van Alphen et al. 2006). EXCIMAP has focussed primarily on the requirements of the directive concerning flood mapping.

In this paper, we present a damage calculation method which can potentially be utilized in the detailed flood risk mapping to be undertaken in Finland. Our case study areas are the settlement of Kittilä in Lapland and the city of Pori at the mouth of river Kokemäenjoki in SW Finland. Kittilä experienced in 2005 a hazardous flood event, which was well documented along the river and in airborne photographs during the peak discharges. Estimates of building-specific damages can be retrieved from damage compensation applications addressed to the government. An economic hazard function can be composed based on the flooded area and the damage estimates. The function allows flood damages to be quantified e.g., per square metre of building area and furthermore, evaluate economic damages for different types of buildings and households. We have transferred the hazard function to the city of Pori and estimated with this formula the potential flood hazards caused by a hypothetical flood event.

METHODS AND DATA USED

Severe floods occurred at places along the Ounasjoki River in northern Finland during the snow melting period in May 2005. At the settlement of Kittilä (67°42′03″N, 24°50′48″E), the water level during peak discharge was 500 cm (MW) above the normal causing numerous buildings to be flooded. In the aftermath of flood, almost 260 compensation applications for flood damage were filed, summing up to a total of 4,5 million euro. Individual damages were well-defined as the law for flood compensation requires stakeholders to specify the nature of damages (e.g., depth and time of inundation in the building, damage to personal property) in order to be compensated by the government. Our aim was to formulate and solve an empirical economic flood hazard function relating flood depth and building type (residential building vs. leisure building) in order to evaluate the potential economic damages for different types of households and quantify the damages in euro per square metre. This information can later be employed in house-specific damage estimates as part of the national flood risk mapping process.

In Kittilä, we divided houses into two categories; one containing residential buildings and the other one leisure buildings. The use of spatial database of flat and building record (Rakennus- ja huoneistorekisteri *in Finnish*, Finnish Population Register Centre, RHR) allowed us to add valuable information in our analyses of recorded damages that occurred in Kittilä This dataset includes information about the floor area and building material as well as the exact location coordinates of the residence. These nation-wide data cover practically all buildings in Finland and are continuously updated by the National Land Survey of Finland.

Thus, by pooling the individual flood damage reports and the RHR-building record we obtained a data set which includes the building type, building material and age, inundation depth, location and economic damages to the building and personal property, to name the most important parameters. The inundation depth may be obtained in two ways. The resident of a flooded building is expected to report in the flood damage compensation form the highest water level. It is also possible to determine the highest water level by defining the inundation area and substituting it with a local DEM. From the 260 damage reports available, we included in our analysis those classified as residential buildings (17 reports) and leisure buildings (30 reports). We excluded from our investigation secondary buildings such as saunas and sheds, as well as buildings from which we had only partial damage information.

This GIS-based estimate of house-specific economic damages in Kittilä was transferred to the city of Pori for a hypothetical flood situation. The monetary euro/square metre damage relation of direct, tangible building damages was applied using a GIS-analysis as follows: First, we determined a 1/250 year flood scenario and the subsequent inundation area in the city of Pori. This allowed us to identify the buildings that will be directly affected by the flood and analyse their location and floor area. This information combined with the damage estimate function derived from Kittilä allowed us to produce a simple formula to quantify economic losses in different parts of the inundated area.

RESULTS

The combination of house-specific damages with the floor area produced a relatively clear correlation for residential buildings in Kittilä (Figure 1). For leisure buildings, however, the correlation was poor probably due to much larger variation in the property values, from simple cabins to fully equipped second homes. This pilot study demonstrated that it is not always possible to automatically produce a reliable inundation depth for use as an explanatory damage variable due to insufficient spatial accuracy of the RHR data. In the RHR, individual buildings are represented by a single point, located often in the geometric centre of the house, which may or may not sit under water depending on the building size and shape and the inundation pattern. Practically all buildings in the analysis were affected by water levels of maximum one metre. More accurate spatial reference might have helped to further divide the damages in classes relative to the water level.

Age of building did not seem to play a major role in accrual of damages based on our limited number of reported damages. Nevertheless, the preliminary results of our research indicate that data provided by reported flood damages (available since 1983) in Finland has potential to support in the future in-depth analyses of house-specific flood-related damage evaluation.

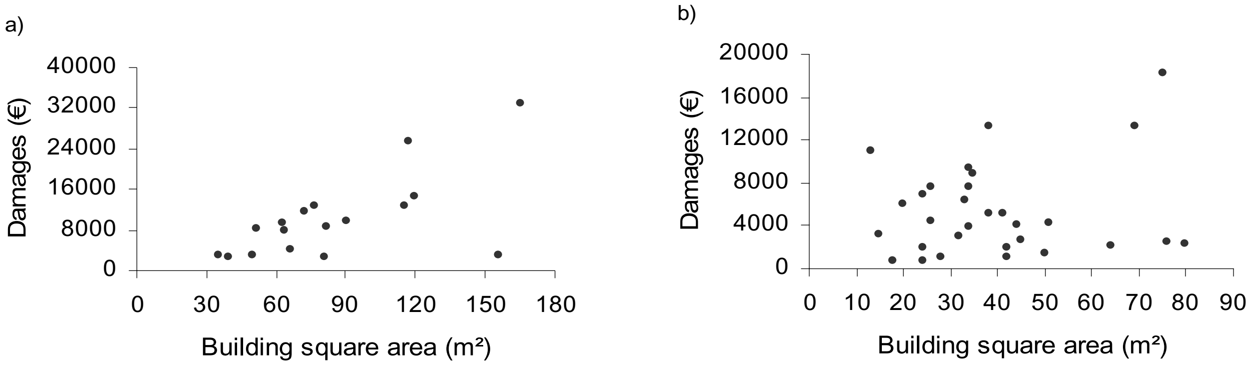

Figure 2. Damages vs. building square area in (a) residential houses and in (b) leisure houses. Case study Kittilä 2005.

Flood hazard analysis in Pori – monetary damages on residential buildings.

We tested residential building flood damage function in Pori region and used a coarse value of 150€/m² as the average economic indicator of flood damage. This value corresponds to the best-fit straight line of data from Kittilä settlement damage for a 100 square meter residence. This highly approximated approach is chosen in absence of more reliable estimates but we consider it to be sufficient for testing the methods of incorporating spatially accurate, household-specific data on potential economic flood damages.

We used a 1/250 year flood scenario and its spatial extent to asses the monetary value of direct damages for residential buildings. Using The RHR (flat and building record) database we could define the number and locations of buildings in risk areas as well as the square areas of individual houses.

Figure 3 presents the visualization of hypothetical direct damages to residential buildings in Pori. We classified the damages in four different classes which are presented on a flood hazard map with circles. Although this damage evaluation is quite straight-forward and considers the building square area as a sole variable, it still delivers reasonably realistic figures. Cumulative monetary losses from individual residential buildings reached an estimate of 70 M€. This number parallels with the earlier study (Koskinen 2006) where the damages for both the residential and leisure buildings were estimated to climb to 77M € in HQ 250 flood event in the city of Pori

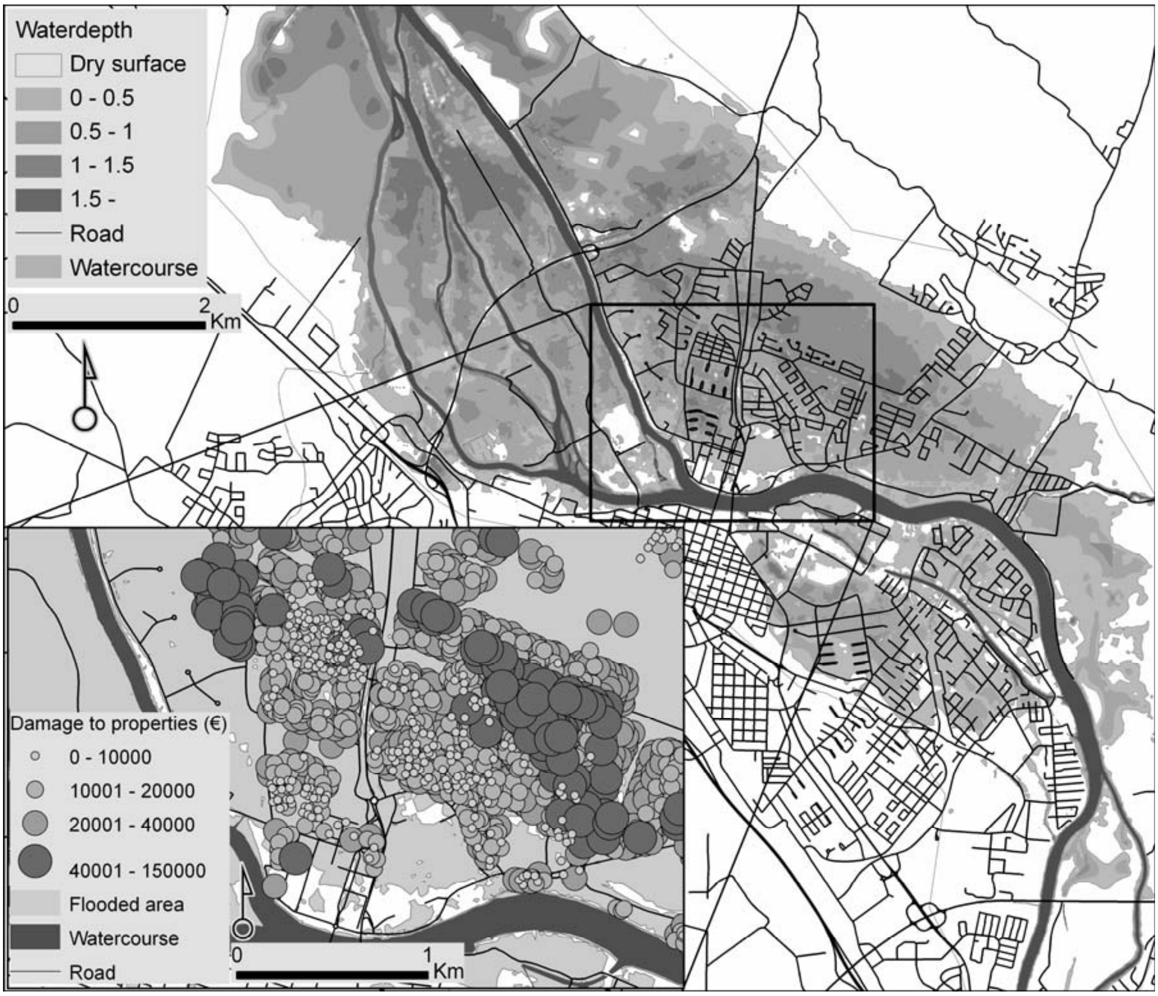

Figure 3. Flood risk map. City of Pori, Finland. Estimates of monetary damages on residential buildings

CONCLUSIONS AND FURTHER RESEARCH

This study introduced a method for applying a well documented flood damage information in to a flood risk mapping process. A good relationship between residential buildings square area and flood damage was found. Nevertheless our analysis was shadowed by a small number of individual flood damage reports at the study site in Kittilä. However, the abundance of flood damage reports available in Finland over the last 20 years will give more insight in to the economic damage evaluation and might even enable us to differentiate the damages as a function of building material, flood depth and as in this example, buildings square area. All the information needed in this venture can be found in the nation-wide RHR-database and the flood damage report database.

Our further research will include analyzing a larger number of flood damage reports and based on this material and spatially accurate building databases we try to discover patterns and similarities in flood damages reported in Finland in the last twenty years. These types of data have not been previously used in GIS-based flood risk mapping in Finland. The results will be useful in detailed flood risk mapping and provide a quantitative estimate of potential economic losses in different peak discharge scenarios.

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Challenges for Water Resources Management in the Changing South West Australia Climate

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ABSTRACT

By 2030 the climate of the south west of Western Australia will likely be drier and hotter. Temperature is projected to rise from 0.5 to 2.1°C by 2030 and by 2070, from 1.0 to 6.5 °C. Rainfall projections are for a decrease by 2% to 20% by 2030 and between 5% and 60% by 2070.
Projections for further declines in runoff from catchments indicate that the south west of Western Australia can expect 5% to 40% less relative to 1990. Further reduction in recharge to aquifer systems is also anticipated. This has significant ramifications for not only consumptive and non-consumptive water uses but also on the way decisions are made in an environment of uncertainty.

Traditionally, water planning has assumed a static environment whereby statistically defensible climatic records were used in decision making. While deficiencies in past approaches are now clearly recognised, projections of plausible climatic futures need to be integrated with socio-political and economic futures when considering the broader environment in which water plans and policy instruments will apply.

Within the backdrop of climate change, the Government of Western Australian is implementing the *State Water Plan 2007* that is consistent with Australia's National Water Initiative (NWI). Broad-scale strategic regional plans will implement the policy objectives of the *State Water Plan 2007* and set the priorities for detailed local water management plans which will be central to decision-making.

The continued progress of water planning will rely on a cooperative effort between the water industry, water resources managers and the community to ensure climate impacts on water resources are recognised and that adequate adaptation measures ensue. Adopting a 'security through diversity' approach to supply and demand options and continued improvement in efficient water use and recycling will advance water policy objectives. The paper concludes by discussing a hydrologic basis for planning with climate change based on recent downscaled climate projections for south west Western Australia.

INTRODUCTION

The global focus on water scarcity has generated active reform agendas within governments and among water users. Australia-wide water reforms have been largely driven by the Commonwealth Government's National Water Initiative (NWI) that was first released in 2004. Western Australia has set a reform agenda consistent with the NWI through the recent *Government Response to A Blueprint For Water Reform in Western Australia* (Gov of WA, 2007) and the *State Water Plan 2007* (Dept of Premier and Cabinet, 2007). Water reforms at both state and national levels are now being consolidated through respective legislative reform agendas.

The South West Land Division of Western Australia, the region most affected by climate change, is an area of approximately 80 to 100 thousand square kilometres where more that 80% of the State's population live. Perth, the State's capital, is the main business centre and the largest city with a population of over 1.5 million. Communities in the south west region of the South West Land Division are concentrated on the region's coastal plain which overlies a deep sedimentary basin with large groundwater aquifers that are used for public water supply, industry, and agriculture. To the east of the approximately 50 km wide coastal plain lie the forested Darling Scarp catchments that occupy high rainfall (800 to 1000 mm/y) areas where 13 large reservoirs capture and store winter runoff for public water supply.

The combination of declining groundwater levels in the Perth region and the lowest recorded reservoir levels has accelerated water resources management and planning for both self-supply (82% of State use) and public water supply (18%). In response, Government commissioned the first major desalination project in Australia at Kwinana immediately south of the City of Perth. The plant commenced full operations in June 2007 to supply 45 GL/y to the Integrated Water Supply Scheme (IWSS) which connects major water supply sources that serve Perth and surrounding regions.

A strategic regional water plan for the South West region is now nearing completion. The regional plan identifies issues, options and priorities for action to implement the seven key policy objectives in the *State Water Plan 2007*. During the plan's development a controversial proposal to pump 45 GL/y from the South West Yarragadee aquifer to supply the Perth region was shelved by the State Government. Instead, Government announced a second major desalination plant (supplying from 45 to 90 GL/y) to provide additional water to the IWSS for future urban and regional growth. This marks a shift in reliance on traditional surface water and groundwater sources and a more prominent role for rainfall independent sources of water supply. Public opinion was a significant factor in this decision.

In order to grasp the significant shifts in water planning that has occurred over the last quarter century and to understand the basis for future water planning, an appreciation of climatic and institutional change is required.

PLANNING RESPONSE TO CLIMATE CHANGE

The changing South West climate – 1975 to 2007

South-western Australia's reliable climate experienced an abrupt change of climate in the mid 1970s. The region's Mediterranean climate began experiencing a significant decrease in winter rainfall, as shown in Figure 1, and an associated decrease in stream-flows, as shown in Figure 2. Groundwater recharge also decreased during this period. Water supply systems and water dependant ecosystems began to show the impacts of this shift in climate that was characterised by an absence of 'wet' winters and the consequent drawing down of reservoirs, superficial aquifers and wetlands.

A decrease in rainfall for the quarter century ending 2001 was in the order of 10% to 15% less than the previous 50 years. Decreased rainfall has occurred predominately in early winter with less rain days and less rain on wetter days. The drop in rainfall has already significantly shifted the hydrology of south west catchments and aquifer systems. The last nine years of runoff into public water supply reservoirs servicing the Perth region is less than one third the levels for the 1911 to 1975 period, an average annual reduction of 274 GL. This decline corresponded to a period of rapid regional growth.

A growing reliance on groundwater supplies from the sedimentary aquifers underlying the Perth region has contributed to a progressive drop in groundwater levels and water in wetlands that extend along the Swan Coastal Plain. An assessment of 110 hydrographs on the shallow aquifer under and to the north of Perth on the Gnangara Groundwater Mound concluded that reduced rainfall is the major cause of declining groundwater levels that have dropped as much as four metres since 1969 (Yesertener, 2007). The absence of 'wet years' has exacerbated the performance of hydrologic responses as a higher percentage yield for both groundwater and surface water systems occurs when natural systems are primed with replenishing rains.

A concerning aspect of this decrease in rainfall is the coinciding trend of the increase in atmospheric pressures for this region and the decreased rainfall projected for future decades due to global warming. The south west has experienced a warming trend over the last 50 years that corresponds to national and global trends. This warming can be expected to increase evapo-transporation that further reduces the runoff and recharge to water systems.

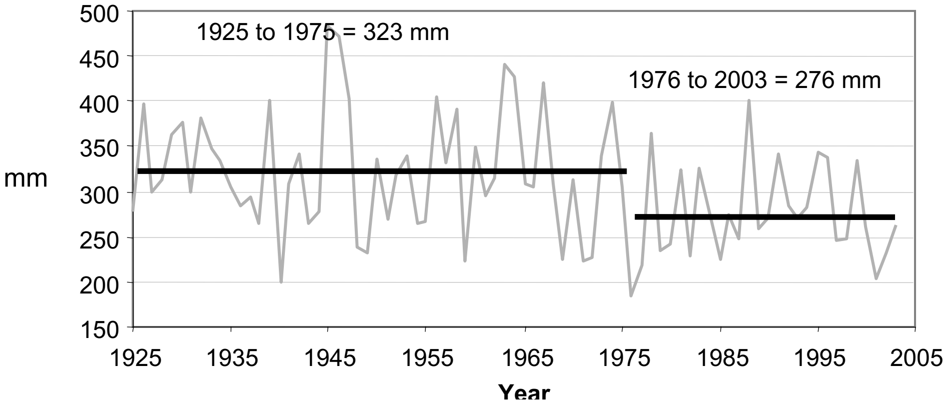

Figure 1. Winter (May-October) rainfall for the South West Land Division, 1925 to 2003

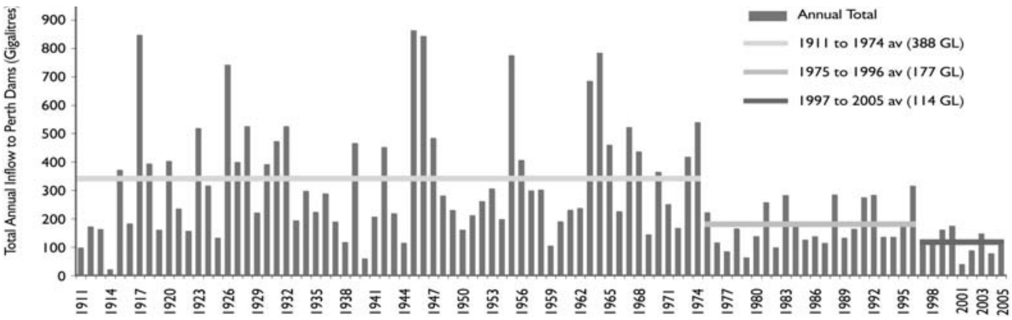

Figure 2. Streamflow to Perth's water supply dams, 1911 to 2005

The water industry's ability to respond to the drying climate was facilitated by the climate research in the early 1990s, which helped establish the Indian Ocean Climate Initiative (IOCI – www.ioci.org.au) in 1998. IOCI is a research partnership involving the State of Western Australia, CSIRO and the Bureau of Meteorology. IOCI recently concluded that there is increased confidence in attributing the causes of observed rainfall decline in south west Western Australia to changes in greenhouse gas concentrations (Ryan and Hope, 2006). The concern for decision-makers is that even if the shift is a temporary phenomenon, the hope of reverting to previous climate regimes is diminished by the impacts of global warming projections.

Institutional factors in Western Australia's water planning

The issue of climate variability masking evidence of climate change was a conundrum that water planners struggled with particularly when justifying design assumptions that were not aligned with long-term statistical records. A review of the south west water sources in 1987, following the climate change focus generated by the 1985 Villach conference and CSIRO's publication of the 1987 national climate change scenarios, considered the implications of the then projected 20% decline in rainfall by 2040 and a corresponding decline in streamflow of 40%. The outcome of that review recommended an incremental strategy be adopted for responding to the expectations of a drying climate. A lowering of estimated surface water system yields ensued, as did early scheduling of new groundwater source developments and a more direct promotion of demand management. However, the step-decline in rainfall was magnified several fold, as observed in dam inflows, and the abrupt change forced planners to adapt at a rate much greater than anticipated. The advancement of water source development proved difficult on a number of fronts, particularly when justifying environmental impacts and in light of the increased capital investment which at that time was estimated to require an initial $500 million.

A major new strategic water plan for *Perth's Water Future* (Stokes *et al,* 1995) was published following further downward adjustments to the assumed yield of the IWSS. At this time there was no regionally relevant science to support a conclusion that the climate had taken a non-linear step change.

Impacts of climate change became increasingly apparent during the decade to 2005. Public water supply source options defined in *Perth's Water Futures* were taken up at a rate significantly in advance of projections. The accelerated pace coincided with a series of Government responses to the 'water crisis' that centred on very dry years around the 2001 period. These actions were profiled in the 2003 *State Water Strategy* and were central to avoiding severe water restrictions. A retrospective assessment now indicates that approximately $1.5 billion was spent on water source development over the last 10 years and an estimated $2 billion will be needed over the next five years.

The planning response to the drying climate should not be idealised as the water sector had other issues to deal with which affected its strategic response at both regional and national levels. In the mid 1990s in Australia, the water sector's policy scene was dominated by a national agreement on micro-economic reform in the water industry. This change occurred at a time when climate change impacts were affecting south west water resources. Implementation of national micro-economic reforms coincided with a decline in monitoring programs and the rapid erosion of integrated planning. The water industry's relatively effective response to the major climate impacts was driven more from the 'front line' than from policy leadership (Sadler, 2002). Another symptom of the 1995 to 2006 era was the difficulty experienced by Government water managers and regulators when responding to the changing policy and political environment that was forcing change and challenging institutional arrangements. This period also reflected the need for management styles that embraced community engagement on a meaningful and inclusive level, including consideration of climate change impacts.

In the 2004/05 period, the State Government continued to advance its water reform agenda by announcing the formation of the Department of Water in late 2005. One of the first initiatives announced was the development of a State Water Plan.

State Water Plan 2007

The Government of Western Australia released the *State Water Plan 2007* in early 2007. The *Plan* provides a strategic policy and planning framework to plan and manage water resources in Western Australia. The *Plan* also outlines the existing knowledge of water resources, describes their intrinsic value to the environment, local and Indigenous communities and their importance as a foundation for economic prosperity. The *State Water Plan 2007* involved consultation at all levels in the community to ensure stakeholders and water users throughout Western Australia were actively involved in steps to secure the States' water future. Importantly, the *State Water Plan 2007* recognises that reduced rainfall from climate change and a projected 40% population increase by 2030 requires a concerted effort by Government and the community to ensure a sustainable water future. The *Plan* sets a goal to recycle 30% of water use by 2030, up from the previous target of 20%. A vision for water resources management in Western Australia is supported by seven objectives.

Vision: Our precious water resources are managed and developed in a sustainable manner to maintain and enhance our environment, cultural and spiritual values, our quality of life and the economic development of the State.

- Use and recycle water wisely
- Plan and manage water resources sustainably
- Invest in science, innovation and education
- Protect ecosystems, water quality and resources
- Enhance the security of water for the environment and use
- Develop water resources for a vibrant economy
- Deliver services for strong and healthy communities.

Regional Water Plans

The first phase of regional water planning was initiated in 2006 with a focus on the South West region. Regional water plans will show the regional application of the policy objectives and a vision that is aligned with the *State Water Plan 2007* and a whole of water cycle approach to water management.

Regional plans are approved by the Minister for Water Resources and affect most agencies, the community and several levels of government. Active engagement with stakeholders and recognition of involvement in planning is vital for the development of ownership and a commitment to regional plans. Consultation allows both gathering of information that is community based and technical, as well as sharing concepts and understanding of major issues. The consultation process has revolved around groups geared to State agencies, the South West Water Forum – key regional stakeholders representing peak water user groups, and Indigenous water groups that have provided valuable input on 'caring for country'. Industry has been involved in sectoral workshops designed to clarify sectoral-specific issues in the region and dialogue on approaches industry groups are able to support. The emphasis of sectoral workshops has been on sharing solutions to strategic issues.

Partnering with the community was a key issue in the South West Water Plan along with:

- reduced rainfall and climate change
- protecting and managing waterways and wetlands
- drainage management and flood protection
- how much water is needed?
- how much water can be taken?
- doing more with less
- acid sulphate soils
- tree plantations and farm dams
- reducing river salinity
- nutrients and algal blooms

A HYDROLOGIC BASIS FOR PLANNING WITH CLIMATE CHANGE

To prepare a new series of water management plans using the best available science, estimates of the range of rainfalls, streamflow and recharge likely to occur over the subsequent decade are required. Explicit studies of the effect of increased greenhouse gas emissions on reducing rainfall and streamflow in South West region were carried out for the Stirling catchment (Berti *et al,* 2004). The IPCC SRES A2 emission scenario was used to estimate greenhouse gas emissions and climatic conditions in 1990 and 2050. The change in expected CO_2 concentrations under this scenario represented a 70% increases in CO_2 concentrations by the middle of the 21st century. Statistical downscaling of rainfall and temperature data from the CSIRO (Mk3) GCM outputs were used to obtain multiple sets of daily data across the Stirling catchment for sets of twenty years for the two climatic periods studied. The LUCICAT hydrologic model was used to estimate streamflow responses for the two climatic conditions, deriving streamflow statistics for 20 year sequences centred on the climatic conditions representative of 2050 and 1990. Results showed that under the IPCC SRES A2 emission scenario the Stirling Dam catchment rainfall decreased by 11% and streamflow by 33% by 2050, relative to the 1990 base. If the effect of increased temperature were assumed to increase evaporation potential by 10%, then streamflow was projected to reduce by 40% by 2050. Studies demonstrate Global Circulation Models (GCM) have difficulty showing dramatic changes over shorter time periods, as natural variability tends to pre-dominant. Nevertheless, hydrologic models that use modified rainfalls and evaporation potential, based on averaged changes derived from GCM simulations, provide indicative estimates of future hydrologic conditions.

While acknowledging the many uncertainties in projected climatic trends, realistic estimates for a range of rainfall and hydrologic responses are needed as input to current planning studies. A review of projected climate impact studies (Berti *et al,* 2007; Jones *et al*, 2006) and an interpretation for the 2015 planning horizon relative to 1990 supports a reduction in mean annual streamflow as shown in Table 1. A further assessment of streamflow to the 2030 regional water planning horizon, using results from Berti *et al* and the assumption of a 10% increase in evaporation, is also shown in Table 1.

The approach proposed involves the generation of sequences of rainfall and streamflow for use in simulations of groundwater and surface water systems. The statistics of a monthly series of rainfall and streamflows can be determined from records for the period 1975 to 2005. The mean annual flows can be corrected for the reductions proposed in Table 1. The monthly means can be similarly corrected assuming coefficients of variation stay the same. Consequently, standard deviations would be corrected in a similar way to the monthly means. The corrected set of monthly statistics can be used as input to statistical generation packages to produce equally likely sequences of rainfalls and streamflows at multiple sites. The approach preserves annual and monthly means, standard deviations, statistical distributions, cross correlations between sites and any serial correlation in the data. The resultant sequence of synthetic data can be used to simulate complex water resource systems. A rules based approach to water allocation and the administration of entitlements based on a share of available resources (consumptive pool - varies with hydrologic inputs in a defined period) can then be applied.

Table 1. – Hydrologic estimate for 2015 and 2030

Statistic	Reduction from 1990 to 2015	Reduction from 1990 to 2030
Mean annual rainfall	4%	7%
Mean annual streamflow	11%	27%

A discussion on impacts of climate changes on groundwater (Commander, 2000) outline the variability of groundwater responses and the need for improved knowledge of recharge responses.

DISCUSSION AND CONCLUSIONS

The considerable progress and commitment to water planning in Western Australia demonstrates a consolidated approach in response to both State and Commonwealth water reforms. However, community-wide awareness of a revised approach to water planning that accounts for climate change has only recently received wider acceptance on a social-political level. This has highlighted how hydrologic and social changes will continue to challenge the adequacy of adaptive responses at institutional, community and political levels. Guidance provided by the State Water Plan 2007 and Government responses to water reforms will be instrumental to Western Australia's water future.

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Impacts of Glacial Recession on Water Movement between the Agricultural Oasis and Desert in the Heihe Watershed, Northwestern China

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ABSTRACT

The Heihe River is the second largest inland river in arid Northwestern China, with a drainage area of 128,000 km^2. Its glacial headwaters, middle agricultural oasis reach, and lower desert reach make up 21.9, 43.6, and 34.5 percent of the watershed respectively. In recent years, the shrinking glacial area and increased agricultural irrigation have reduced river flows and depleted lakes in the lower reaches. This paper describes the preliminary work of adapting the U.S. Department of Commerce's National Oceanic and Atmospheric Administration's Distributed Large Basin Runoff Model to the Heihe Watershed for understanding glacial/snow melt, groundwater, surface runoff, and evapotranspiration, and for assessing hydrological impacts of climate change and glacial recession on water supply in the middle and lower reaches of the Watershed.

Keywords: glacial recession, hydrologic modeling, distributed large basin runoff model, (DLBRM), Heihe Watershed in Northwestern China, and water shortage.

INTRODUCTION

Dry lands (including arid, semi-arid, and dry humid areas that are characterized by scarce and unpredictable precipitation) account for approximately 41 percent of global land surface and are home to over 38 percent of the world population of 6.5 billion (Reynolds et al. 2007). Water is a scarce but key resource in dry lands. Proper management of the limited water resources is essential to ensure the welfare of human beings and the sustainability of dry land ecosystems. During the past few decades, however, improper water resource management has resulted in numerous problems worldwide, including poor food security, increased human diseases, conflicts between different users, limitations on economic development and human welfare, desertification, salinization, sand storms, water pollution, and so forth (United Nations World Water Development Report 2003; Reynolds et al. 2007). In Central Asia, for example, increasing irrigation demands have resulted in the reduction of the Aral Sea, once the world's fourth largest lake, by 50 percent and the lowering of its water level by 16 m, depleting fisheries and wildlife habitat, endangering flora and fauna, and increasing respiratory and digestive diseases from inhalation and ingestion of blowing salt and dust (Micklin 1994). In China, the increased withdrawals from the upper and middle reaches of the Yellow River depleted groundwater in much of the basin and contributed to desiccation (i.e. no measurable flow in the river) of the lower reaches in 22 of the years between 1972–2000. The desiccation has created serious economic and environmental problems throughout the North China Plain, including water rationing, under-capacity industrial production, reduced crop yields, water pollution, wildlife habitat depletion, coastline recession, and sea water intrusion (He et al. 2005). In the face of climate change, population growth, urbanization and globalization, water stresses in dry lands will intensify. To cope with this challenge, it is crucial to accurately model and better understand the impacts of human activities on the dynamics of dry land hydrological systems and develop management scenarios to support sustainable dry land development programs.

China's arid and semi-arid areas cover over 52 percent of its total territory, and rain fed farming accounts for over 50 percent of the total arable land (Agricultural Research in the Arid Areas 1983). Located in arid Northwestern China, the Heihe is the second largest inland river (or terminal lake) in the nation, with a drainage area of 128,000 km^2. From its headwaters in the south to the middle and lower reaches in the north, it flows through Qinghai, Gansu, and Inner Mongolia (Figure 1). Glacial and mountain, agricultural oases, and desert cover 21.9, 43.6, and 34.5 percent of the watershed respectively (Pan and Tien 2001). While glacial/snow melt in the Qilianshan Mountain contributes about 8 percent of the total annual water supply in the basin, the glacier shrank by 29.18 km^2 from 1960 to 1995 (Feng et al 2002). Agricultural irrigation water supply in the oases comes mainly from groundwater withdrawals. Since the 1970s, the increased withdrawals for agricultural irrigation in the Hexi Corridor (see Figure 1) have depleted much of the river flows (in some years, the river drys up completely for some time) to the lower reaches, shrinking East Juyan Lake and drying up West Juyan Lake, endangering the aquatic ecosystem, accelerating desertification, and intensifying water conflicts between the middle and lower reaches. To mitigate water conflicts and rehabilitate West Juyan Lake, the State Council issued a "Water Allocation Plan for the Heihe Watershed Mainstream" in 1997, mandating water allocation to the lower reaches each year (Pan and Tien 2001; Feng 2002). A number of water saving initiatives such as water quota, water rights, and transfer have been initiated to make effective use of water resources in the Heihe Watershed. While a number of studies have been done in the Heihe Watershed (Feng 1999; Feng et al. 2002; Pan and Tien 2001; Cheng 2002), the magnitude, spatial and temporal distribution, and transfer mechanism of the Heihe hydrological system are still not well understood, especially in the face of climate change and urbanization. This gap, together with the lack of a comprehensive implementation plan has slowed down implementation of the State Council's water allocation plan. To address this problem, we are collaborating with the Chinese Academy of Sciences' Cold and Arid Regions Environmental and Engineering Research Institute (CAS CAREERI) to simulate the Heihe hydrological system and to evaluate the hydrological impacts of climate change and glacial recession. This paper describes the preliminary work of adapting the US Department of Commerce's National Oceanic and Atmospheric Administration's (NOAA) Great Lakes Environmental Research Laboratory (GLERL) Distributed Large Basin Runoff Model (DLBRM) for understanding hydrological processes of the Heihe Watershed. We first describe the physical features of the Heihe Watershed and then introduce the structure, input, and output of the DLBRM. Finally we discuss its application to the Heihe Watershed. Since the research is still in progress, the paper reports climate change scenarios to be used in the DLBRM for assessing the impacts of glacial recession and water shortage on the hydrology and agricultural production in the watershed.

METHODS

The Study Area

From the headwaters in the south to the lower reaches in the north, the Heihe Watershed can be physically divided into the Qilianshan Mountain, the Hexi Corridor and the Alashan Highland (Figure 1) (Feng et al. 1999). The Qilianshan Mountain is situated at the south of the Watershed, with a peak elevation of 5,584 m. It is covered by ice and snow all year round above 4,500 m. Between 3,600 to 4,500 m are the mixed alpine meadow and permafrost. In the 1,900--3,600 m range, the mean annual precipitation is 250—500 mm and the main vegetation is forest and grassland. Below 1,900 m, the landscape is dominated by hilly desert or grassland desert with mean annual precipitation of 200—250 mm (Feng et al. 1999). Located in the middle reaches of the Heihe Watershed, the Hexi Corridor is situated between the southern Qilianshan Mountain and the Beishan Mountain, stretching 40—60 km from south to north (Fig.1). Over 90% of the total agricultural oases and over 97 percent of the Heihe Watershed's more than 1.8 million inhibits are concentrated in two metropolitan areas: Zhangye (population 1.25 million in 2000) and Jiuquan (population 0.49 million in 2000) in the Corridor. Irrigation supply is mainly from groundwater pumping. North of the Hexi Corridor is the Alashan Highland (elevation 1,000 m), an extremely dry desert with an annual precipitation below 50 mm. Spotty oases appear intermittently along the streams, lakes, and irrigation ditches. Since it is extremely dry, the Alashan Highland is a large source of frequent sandstorms.

Water shortage is a chronic problem in the Heihe Watershed. The total annual mean water supply in the watershed is approximately 3.48 billion (10^9) m^3 and nearly 90 percent of the flows are generated in the Qilianshan Mountain. The total annual water withdrawals in the Heihe in 1995 were about 3.36 billion m^3 and 86 percent of that was used to irrigate 288,000 ha of farmland mainly located in the Hexi Corridor (Pan and Tien 2001). Water deficits range from 0.32 billion m^3 (normal years with 50%, non-exceedance), to 0.57 billion m^3 (dry years with 75% non-exceedance), and 0.82 billion m^3 (drought years with 95% non-exceedance) respectively (Pan and Tien 2001). Water conflicts have been high between water users in the Hexi Corridor and those in Alashan Highland in the lower reaches, particularly in implementing the State Council's water allocation plan to deliver water to the lower reaches for rehabilitation of the West Juyan Lake (Pan and Tien 2001).

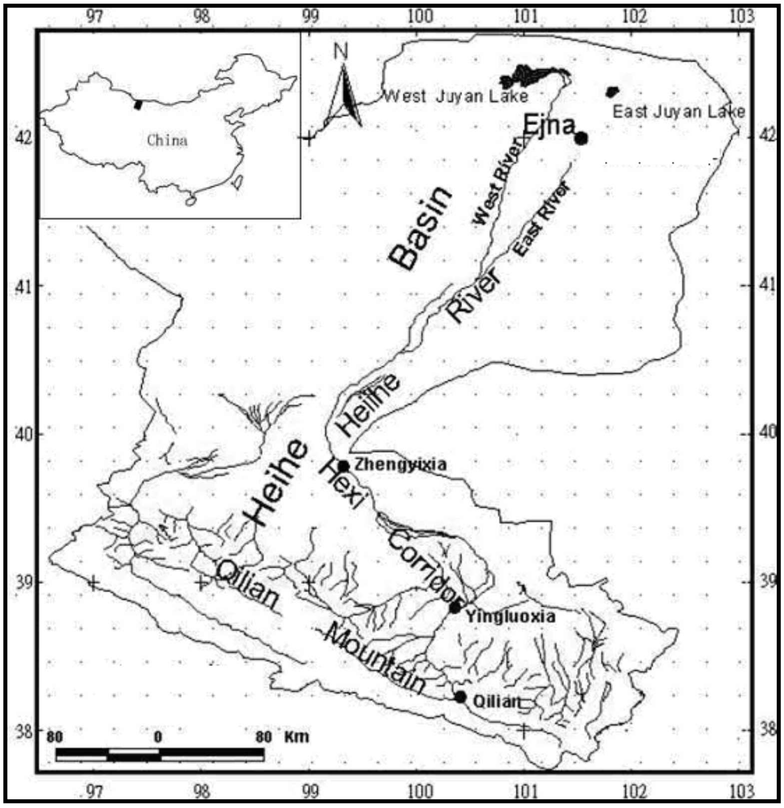

Figure 1. The boundary of the Heihe Watershed (Source: J.H. Si of CAREERI 2007)

Description of the DLBRM

The DLBRM represents a watershed by using 1-km^2 grid cells. Each cell of the watershed is composed of moisture storages of the upper soil zone (USZ), lower soil zone (LSZ), groundwater zone, and surface, which are arranged as a serial and parallel cascade of "tanks" to coincide with the perceived basin storage structure (Figure 2). Water enters the snow pack, which supplies the basin surface (degree-day snowmelt). Infiltration is proportional to this supply and to saturation of the upper soil zone (partial-area infiltration). Excess supply is surface runoff. Flows from all tanks are proportional to their amounts (linear-reservoir flows). Mass conservation applies for the snow pack and tanks; energy conservation applies to evapotranspiration. The model computes potential evapotranspiration from a heat balance, indexed by daily air temperature, and calculates actual evapotranspiration as proportional to both the potential and storage. It allows surface and subsurface flows to interact both with each other and with adjacent-cell surface and subsurface storages. The model has been applied extensively to riverine watersheds draining into the Laurentian Great Lakes for use in both simulation and forecasting (Croley and He 2005; 2006; Croley et al. 2005; He and Croley 2007). The unique features of the DLBRM include: 1) use of readily available climatological, topographical, hydrological, soil, and land use databases; 2) applicability to large watersheds; and 3) analytical solutions of mass continuity equations, (mathematical equations are not shown here due to space limitations; for details, see Croley and He 2005; 2006; He and Croley 2007).

DLBRM inputs include, for each cell, flow direction, slope, land use, Manning's coefficient (*n*) values, soil texture, and USZ and LSZ depths, available water capacity, and, permeability, as well as daily precipitation, air temperature, and solar isolation,. DLBRM outputs include, for every cell, surface runoff, ET, infiltration, percolation, interflow, deep percolation, groundwater flow, USZ, LSZ groundwater, and surface moisture storages, and lateral flows between USZ, LSZ, groundwater, and the surface.

As the DLBRM considers surface and subsurface interactions and is particularly suitable for continuous simulation of large scale hydrological systems over the long term, it is used to simulate the hydrological system of the Heihe over the period of 1978-2000 at daily intervals. The Heihe Watershed of over 128,000 km^2 is divided into 14,622 cells at resolution of 3 km by 3 km. The databases of land use/cover (2000), DEM (100 m resolution), and watershed hydrography were provided by the CAS CAREERI. Meteorological databases from 22 weather stations for the period of 1978 to 2000 were used to interpolate precipitation and temperature using one of several methods: Thiessen polygon, inverse distance, inverse squared-distance, and linear interpolation over a triangular irregular network (TIN). Daily surface insolation estimates are generated by two methods: (1) from temperature databases by empirical formulae, and (2) reversed-engineered from an available weather generation model as a function of location, day of the year, air temperature and precipitation (Croley and He 2005; He and Croley 2007). Slope and flow direction are extracted from the DEM database. The soil database of 1999 (1:250,000) from the Gansu Province only contains soil types and texture at the soil association level, and depths, water capacity, and permeability of the USZ and LSZ are not available. We are working to incorporate detailed soil sampling data from the CAREERI to estimate those soil parameters. Manning's coefficient values are derived for each grid based on the combination of land use, slope, and soil texture. Six streamflow gauge stations located along the main channels of the Heihe River are used in calibration of the DLBRM as a systematic search of the parameter space to minimize root mean square errors between actual and simulated daily outflow volumes at the watershed outlet. Currently, we are working to derive input variables to and to calibrate the DLBRM.

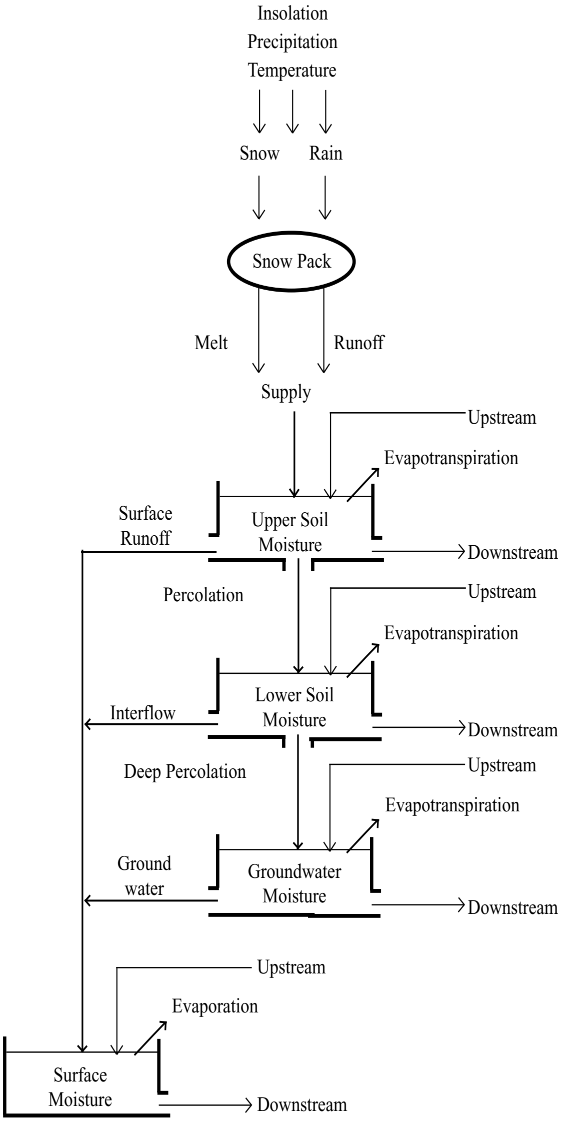

Figure 2. Tank cascade schematic of Distributed Large Basin Runoff

Simulating Impacts of Glacial Recession on Streamflow

Climate change will further intensify water stresses in areas that already suffer from water shortages such as northern China and the Middle East and sub-Saharan Africa countries, decreasing river flows in low flow periods and degrading water quality (UN World Water Development Report 2003). Studies have reported the observed significant increase in annual mean minimum temperature and the decrease in annual mean precipitation rates during the past 50 years in Northwestern China (Varis and Vakkilainen 2001; Fu et al. 2004; Huang and Zhao 2004; Yang et al. 2004). The drying-up of the Yellow River since the 1990s was reported as a result of the decrease in precipitation (-38.2 mm/10 yr) and the increase in evaporation (+52 mm/10 yr for pan evaporation) (Yang et al. 2004). Since glacial/snow melt contributes about 8 percent of the total annual discharges in the Heihe Watershed and the glacier has shrunk significantly during the past few decades, we will simulate the impacts of glacial recession on water supply of the Heihe River. Upon calibrating the DLBRM, we will incorporate scenarios of 10 and 20 percent reduction in glacial/snow melt into the model and assess how that reduction would affect the magnitude and distribution of surface runoff, groundwater, evapotranspiration, and basin outflow throughout the Heihe Watershed. Since the simulation results can be examined over individual cells in map format, we will be able to track the spatial distribution of hydrological variables to better understand the partitioning of river flows between the Hexi Corridor of the middle reaches and the Alashan Highland of the lower reaches. Such information will support implementation of the State Council's water allocation plan to rehabilitate the West Juyan Lake.

SUMMARY

The Heihe Watershed is the second largest inland river in China and is a microcosm of China's arid and semi-arid regions. While water shortage is a chronic problem in the Heihe Watershed, the rapidly increasing water withdrawals for agricultural irrigation and urbanization in the populated middle reaches have depleted river flows to the lower reaches, drying up West Juyan Lake and endangering aquatic and terrestrial ecosystems downstream. In the face of climate change and rapid urbanization, water conflicts and stresses will further intensify between water users in the middle reaches and lower reaches in the Heihe Watershed. This paper reports our collaboration with Chinese colleagues to adapt the DLBRM to the Heihe Watershed for understanding water transfers between glaciers, snow pack, groundwater, surface runoff, and evapotranspiration, and for simulating the impacts of reported glacial recession on the Heihe hydrological system. The DLBRM requires multiple databases of climate, land use/cover, topography, and soil but some of the databases such as soil are either not available or incomplete. Thus, we must generate necessary databases anew utilizing new methodologies. While this project is undersway, we are working to simulate the impacts of reduction in glacial/snow melt on the magnitude and spatial and temporal distribution of hydrological components throughout the Heihe Watershed. Once available, we hope the simulation results will support the rehabilitation of the West Juyan Lake in the Heihe Watershed and shed light on sustainable use of limited water resources in the arid and semi-arid regions of China.

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Water Resource Management and Climate in Society

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Keywords: climate adaptation, water resource management, society, risk for climate, baseline, vulnerability

ABSTRACT

Based on the outcomes of the World Meteorological Organization (WMO) Conference on Living with Climate Variability and Change: Understanding the uncertainties and managing the risks (LWCVC) in Espoo, Finland, 17-21 July 2006, water resource management and climate issues are discussed in the context of the interfaces between climatic and social processes as well as of climate risk management. The importance of the baselines is emphasized from the point of view of vulnerability. Also the role of different time horizons is discussed in various water resource management issues. Then the following questions will be addressed: 1) What are the challenges of long-term planning in climate adaptation and mitigation? 2) How does the global water resource management landscape look like and how is it related to the climate system? 3) What are the means through which countries aspire to address both water resource management and climate concerns? 4) Is there any institutional mechanism through which the mutual concerns of water resource management and climate could be addressed in the context of a growing need to take into account social processes and 'mainstream' the climate risk management? and 5) To what extent LWCVC addressed concerns of water resource management and climate in developing countries?

INTRODUCTION

As risks for climate have increased during recent years climate adaptation has been emphasized in climate risk management as a needed line parallel to mitigation. This broadened view brings up new aspects in the interaction between water resource management (WRM) and climate processes. First related to this, challenges of long-term planning on living with climate variability and change are presented. Then based on the outcomes of the World Meteorological Organization (WMO) Conference on Living with Climate Variability and Change: Understanding the uncertainties and managing the risks (LWCVC) this interaction between WRM and climate processes in the context of the society is discussed in terms of means through which countries aspire to address both WRM and climate concerns, institutional mechanisms through which the double concerns of WRM and climate could be addressed in the context of a growing need to take into account social processes and 'mainstream' the climate risk management, and the extent to which LWCVC addressed concerns of WRM and climate in developing countries.

CHALLENGES OF LONG-TERM PLANNING IN CLIMATE ADAPTATION AND MITIGATION

Related to the sectors of LWCVC: decision making, disasters and early warning systems, agriculture and food security, human health and disease control, water resources, and energy and built environments Zillman (2006) gave a cross-cutting presentation on long-term planning for living with climate variability and change.

According to Zillman (2006) it is essential in the planning process to recognize the important distinction between natural and human-induced change and to treat the challenge of living with climate variability and change in its broadest sense i.e. managing the issue (eg through development of greenhouse gas mitigation policies) as well as managing the impacts of climate (eg through strategies for adaptation to the natural variability of climate).

This planning for living with climate variability and change presents the society with the fourfold challenge of:

planning for improved adaptation to the normal natural variability of climate;
planning for adaptation to whatever long-term changes of climate eventually result from anthropogenic emissions of greenhouse gases;
planning to reduce (mitigate) human-induced climate change through greenhouse gas emission reduction; and
planning for adaptation to whatever changes to social and economic systems are implemented in order to keep human-induced changes of climate below “dangerous” levels.

It is important to recognize that the society and the economics are included in these considerations as active partners. In addition many aspects of these challenges are common to the different climate-sensitive social and economic sectors and to both developed and developing countries.

The LWCVC recognized also that, if energy production is the dominant factor in mitigation, water is very probably the most important cross-cutting factor in adaptation. Examples of this are as follows. First, as a human health issue, sufficient availability of drinkable water is a basic issue. Second, floods lead in many cases to major disasters. Third, needs to pump water across a water divide between two nearby water courses in the context of battling against growing drought problems can be foreseen. Already these three examples show that WRM can play either a direct or an indirect role as a cross-cutting factor.

In the current situation both climate adaptation and mitigation measures are pertinent to the long-term planning for living with climate variability and change.

THE GLOBAL WATER RESOURCE MANAGEMENT LANDSCAPE AND THE CLIMATE COMMUNITY

As pointed out by Muller (2006) the engagement of the WRM practitioners in climate discussions has so far been very weak. This might reflect the focus of the discussions on climate change effects and their mitigation rather than on climate adaptation. Based on climate models the climate change community produces scenarios of the future and this has dominated very much the recent climate discussions. At the same time the perspective of the WRM practitioners has been more or less ignored.

According to Muller (2006) Professor Michael Grubb of the UK Carbon Trust pointed out that the infrastructure we build today locks us into patterns of behaviour for many years in the future (Grubb, 2006). This is very true with WRM where the long time scales dictate very much the needs and requirements for the sufficient resilience the society and the shorter-term operative WRM need. ‘Leap-frogging’ in infrastructure (Grubb, 2006) through choices at the leading edge of the long term changes and fluctuations can open huge opportunities in the course of development. To facilitate this both broader and deeper cooperation among the pertinent communities, climate and WRM included are needed, e.g. in estimating proper return values for dimensioning purposes. The era of traditional end-to-end services should give the way for the interactive ones.

It should be emphasized that the primary parameter the WRM practitioners are interested in is the stream flow. However, to predict stream flows under climate change scenarios is an ambitious task where uncertainty is always present. In this context two messages are to be emphasized (Muller, 2006).

First, the climate model results for the future indicate changes both in temperature and precipitation. These changes will usually be amplified in the response of the water systems.

Second, to derive stream flow predictions from the climate model results (temperature and precipitation) the uncertainty grows. As the stream flow consequences represent an important effect on WRM practices the uncertainty has to be coped with even here.

All in all to build resilience into water management systems would be a step towards sustainable development and is critical if the Millennium Development Goals (MDG's) are to be achieved by 2015 (Muller, 2006).

MEANS TO ADDRESS BOTH WATER RESOURCE MANAGEMENT AND CLIMATE CONCERNS

It is recognized with great gratitude the accomplishments of the IPCC to raise the general awareness of the human-induced climate change and its linkages to WRM. Also the media have played a key role in getting this message through. As the climate mitigation is still a great challenge the efforts of the IPCC shall have the needed, on-going support.

It is welcomed that many countries have started to address both WRM and climate concerns to the general public. Here it should be recognized that the material used must be updated frequently enough to keep up with the pace with new pertinent information. It can be foreseen right now that the emphasis on climate adaptation parallel to mitigation will substantially widen the challenges of these efforts, which hopefully attain an on-going status. The inclusion of adaptation would also give a more balanced view of the relevant WRM issues to the general public.

At LWCVC it was pointed out that the general awareness of climate risks is still very limited in relation to the considerable role they play already and which is growing. Therefore it is absolutely vital to include the most pertinent climate issues in general education programs in as many countries as possible. People need to know and hopefully are even encouraged to absorb the basic issues in order to be able to follow and to participate in WRM and climate discussions of general concern. This becomes more and more important as climate risks increase. This general education should be very much outcome-oriented to the needs of the societies so that there is a proper balance between the basic issues raised, including WRM and climate.

INSTITUTIONAL MECHANISMS AND THE MUTUAL CONCERNS OF WATER RESOURCE MANAGEMENT AND CLIMATE

During the very first phases in the design of LWCVC it was recognized that a multidisciplinary and multi-organizational mix of organizers and attendees was vital. As this mix was present at LWCVC and the need of interaction between the various parties was emphasized over and over again, this interaction proved to be fundamental to get the climate information services and users integrated into the society. Also the role of the WRM sector became broader and more balanced than just under the considerations of mitigation and operative hydrology.

One important focus of the climate adaptation is the climate risk management which is in many

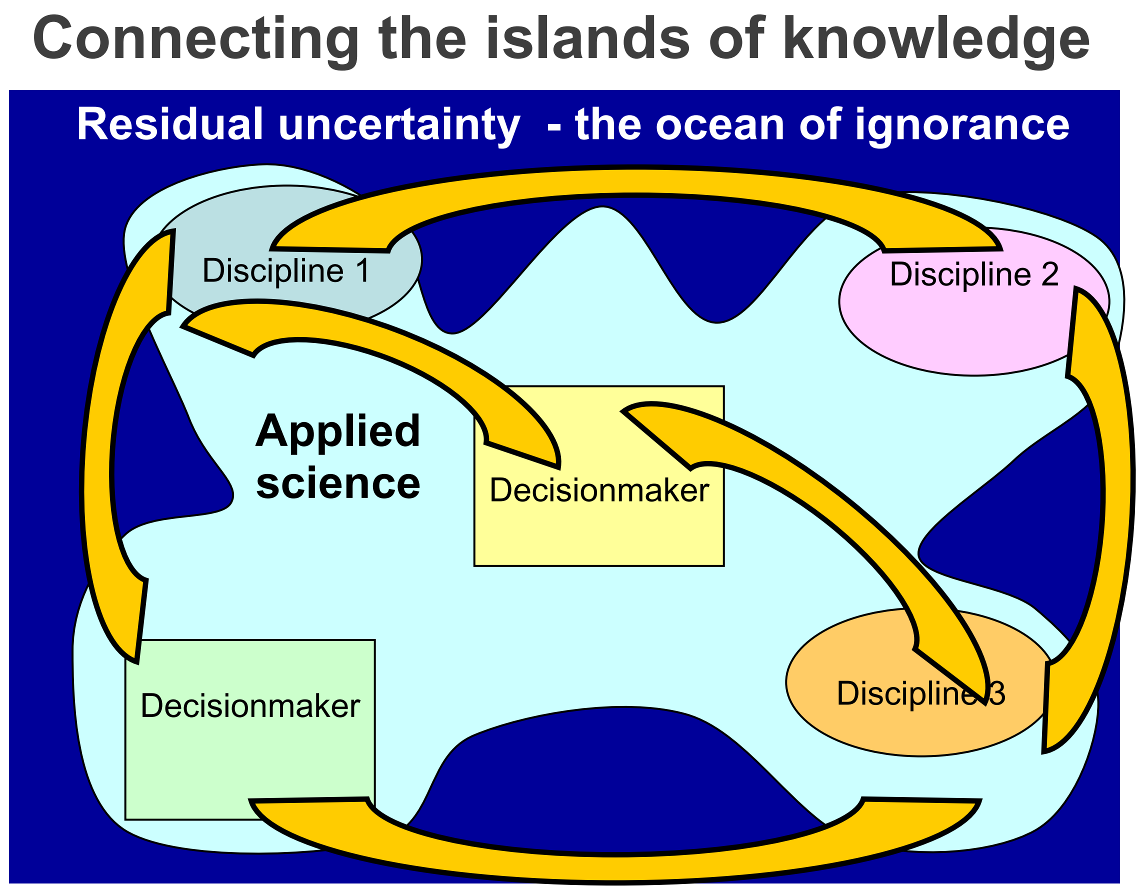

Figure 1. Islands of knowledge in the ocean of ignorance to be connected by the bridges of interaction and cross-cutting factors. Also the role of applied sciences to make the ocean of ignorance shallower is illustrated (Meinke, 2006).

contexts a vital part of the total risk management to support the decision making. The need for the interactive collaboration was illustrated from the point of view of systems science by the following schematic presentation by Meinke (2006).

In this scheme the knowledge acquired by the different disciplines and decision makers is presented as islands in the ocean of ignorance. As long as these islands are isolated they do not know the information of the other islands. According to the scheme there are two ways to improve the situation. One is to build bridges between the islands and these bridges illustrate the interaction between people as well as the role played by different cross-cutting factors. The other alleviation is to make the ocean of ignorance shallower by studies based on applied sciences. This is one way to illustrate the challenges we have when we integrate our knowledge to support the decision making. In integrating WRM and climate factors into the society all these aspects are present. LWCVC recognized that WRM is one important cross cutting factor in many climate adaptation issues, but even more fundamentally the essence to bring in the pertinent social processes was discussed and acknowledged.

In his work Meinke (2006) emphasizes the outcome-oriented approach so that the objectives of the climate information user are taken genuinely into account. In translating climate information into real-life action three components are essential: salience as the perceived relevance of climate information, credibility as the perceived technical quality of information and legitimacy as the perception that the system has the interests of the users in mind and at a minimum is not just a vehicle for pushing the agendas and interests of other actors.

The institutional mechanisms through which the mutual concerns of WRM and climate can be addressed cannot restrict their view any more solely to WRM and climate processes. The society with its dynamics has to be taken into account in a properly interactive way and this is a big challenge still much ahead of us.

So far depending on the society and the culture different approaches to build appropriate institutional mechanisms have been adapted. One possible way is to establish a genuinely multidisciplinary institute which has the needed flexibility to tackle problems of different character and still has the necessary resilience for dynamic interactive collaboration. The International Research Institute for Climate and Society at Columbia University (IRI) is one of the very few, if not the only one institute of this kind. Much of its work is field work in various parts of the world including developing countries. In this sense the IRI is not only an institute of itself, but has a wide network and is to a high degree outcome-oriented in its work where collaboration with the local people is essential. The focus in WRM issues was very much on renewable sources and especially on hydro power generation and reduced risk on flood damage through improved reservoir operation (Tana River system, Kenya).

Australia has developed its institutional mechanism very much around the needs of agriculture. These activities are outcome-oriented and based on a well established network, e.g. in Queensland, where Meinke (2006) applied his new paradigm.

Europe has so far acted very much on national level without any clear cohesion in its efforts. Inspired by LWCVC it is expected that the development of the European institutional mechanism on climate risk management, including WRM, can be foreseen to start in the near future.

Regardless of the particular way to approach the institutional mechanisms relevant to the WRM and climate issues Sachs (2006) pointed out at LWCVC the need of a systematic approach rather than focusing the activities just on some few areas.

WATER RESOURCE MANAGEMENT AND CLIMATE CONCERNS IN DEVELOPING COUNTRIES

During the LWCVC it could be seen that also India has quite a lot of activities in climate risk management in the context of WRM. It was interesting to see, that not only the climate change but also the natural variability of climate is an important issue in this monsoon region where the farms rely on rain-fed agricultural practices. As an example, the recent consecutive years (2001-2004) of severe drought in a semi arid region of India led to peanut crop failures. To alleviate this sensitivity to the climate risks various adaptive farming practices were explored by the Indian Institute of Science in Bangalore in cooperation with local farmers. This is one example of interactive multidisciplinary responses, including some new WRM practices with small scale reservoirs, to local needs.

In Africa in much of its sub-Saharan regions rainfall varies highly and the rain-fed farming practices are very sensitive to this variability. However, here the extent to which irrigation is used is extremely small. According to Muller (2006) the New Partnership for Africa’s Development (NEPAD) from the African side and the World Bank from the donors side have prioritized the promotion of the irrigated agriculture.

In LWCVC it was encouraging to see quite a few representatives from developing countries. It is hoped that the on-going processes recommended to be started by the LWCVC would cover also the WRM and climate issues pertinent to developing countries.

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Climate change signals in streamflow data in the Nordic and Baltic region

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ABSTRACT

The projected climate change in the Nordic and Baltic region is expected to cause a warmer and wetter climate and thus an intensification of the hydrologic cycle. Studies of such changes include attempts to detect climate change signals in historical data. This was the focus of the 'Statistical Analysis' group in the Climate and Energy (CE) project and the results are presented in this paper. The studies include (i) trend analysis of historical streamflow records in the Nordic and Baltic countries (ii) a comparison of regional temperature, precipitation and streamflow in the Nordic countries and (iii) a comparison to scenarios. The trend studies in the Nordic and Baltic region showed that changes in annual streamflow were governed by changes in precipitation whereas trends in seasonal streamflow and extremes to a larger extent were influenced by changes in temperature. This was also reflected when comparing the regional time series of temperature, precipitation and streamflow. The qualitative comparison of these findings to available streamflow scenarios for the Nordic region, showed that the strongest trends found are coherent with changes expected mainly due to a temperature increase in the scenario period, for example increased winter discharge and earlier snowmelt floods. However, there are also expected changes that were not reflected in the trends, such as the expected increase in autumn discharge and autumn floods. These are changes mainly caused by an expected increase in precipitation. Hence, the observed increase in temperature strongly affects the hydrological regimes. This means that the temperature increase caused by human induced climate change, already affects streamflow in the Nordic countries.

INTRODUCTION

Studies of climate change traditionally include elaboration of possible scenarios for the future and attempt to detect a climate change signal in historical data. The latter type of study looks for trends and also establishes knowledge about the natural climatic and hydrological variability. This paper focuses on detecting climate change signals in historical streamflow records. In addition, regional data sets are compiled and used to compare both recent years and climate change scenarios with long-term historical observations. Finally, to see if observed trends in streamflow fit with projected scenarios, a qualitative comparison between the observed trends and available streamflow scenarios is made.

Individual national studies of trends in climate and hydrology in the Nordic countries (for example Lindström and Bergström, 2004; Førland *et al.*, 2000; Ovesen *et al.*, 2000; Hyvärinen, 1998; Jónsdóttir *et al.*, 2006) show that there can be considerable differences between regions. An overview of recent studies of long time series of precipitation, temperature, streamflow and other hydrological variables in the Nordic countries can be found in Hisdal *et al.* (2003). The national studies vary both regarding the period and variables analysed. To make a qualitative estimate of regional differences in the changes found, comparison between the national studies is possible. However, the results would be uncertain due to the various time periods analysed. To study the regional distribution of changes, there is a need to study data from several countries and to include a common time period. The latter is important because the trend or changes found will be strongly influenced by the time period studied. A previous Nordic study on regional differences in trends focused on annual and seasonal streamflow, and on the time period 1930-80 (Hisdal *et al.*, 1995). Meanwhile, streamflow records have been updated, and a similar study is possible for a longer period. Enhanced climate change may result in stronger and longer lasting changes in streamflow, so that the likelihood of change detection might grow (Kundzewicz, 2004). This is an argument for continuous examination of updated streamflow records, including an updated 'pan-Nordic' study to identify larger scale regional differences in streamflow in terms of non-stationarity and climate variability, and possible consequences for the energy sector.

The main objective of this paper is to investigate if streamflow has changed in the Nordic countries and if potential changes can be attributed to changes in climate. The following sections describe the data analysed, the method applied, results and conclusions.

DATA AND METHODS

A total of 232 streamflow records with an average length of 84 years of daily data from the Nordic and Baltic countries, were analysed. The data were selected to cover the whole region with a common time period, including 2002. The record length enables documentation of changes at inter-annual time scales and testing for trends, and these data were used to study trends in annual, seasonal and extreme streamflow (flood and drought). The data from the Nordic countries are stored in a common database, a Nordic version of the European Water Archive (EWA) of the Flow Regimes from International Experimental and Network Data (FRIEND) Project (Rees and Demuth 2000).

The criteria for selecting series were that the records should be, as far as possible, unaffected by human induced changes in the basin, and that the records should be as long as possible. The longest series will often be affected by human activities in the basin, causing various forms of in-homogeneities. The series were therefore classified into three categories: series only suitable for analysis of annual values, series also suitable for analysis of monthly values and series also suitable for analysis on a daily level. As the time period selected will affect the trend, it is important that a common time period is studied when comparing trends in different regions. At the same time as long time series as possible are important to study long term variability. A best possible Nordic and Baltic coverage required a relatively short period to be selected (1961-2000 for the Nordic region, 1961-2003 for the Baltic region). This period encompasses the total data set (232 stations). Two additional sets of stations, 1941-2002/2003 (170 stations) and 1920-2002/1922-2003 (109 stations) were chosen to investigate longer-term trends. The slight difference in record length between the Nordic and Baltic countries is not assumed to influence the results. Analyses of trends in seasonal streamflow and extremes further reduce the number of stations. A minimum number of stations are found for the analysis on a daily level for the period 1920-2002. The spatial coverage of data is not uniform as a larger number of long records from pristine basins are available e.g. in Norway and Denmark as compared to Sweden, Finland and Iceland. This has to be considered when the results are discussed. However, the dataset comprises a good-quality; long-term set of homogeneous series of adequate spatial resolution with a minimum of human influence to detect trends caused by climate changes, natural or human induced.

A simple non-parametric trend test, the Mann-Kendall test (two-sided), with a 5% significance level, frequently applied to detect trends in hydro-climatologically time series, is applied. This test is non-parametric and searches for a trend in a time series without specifying whether the trend is linear or nonlinear. A 5% significance level implies that there is a five percent probability to incorrectly reject the hypothesis of no change and detect a trend, when no trend is present.

An additional set of monthly regional index series of temperature, precipitation and runoff were compiled for 8 Nordic regions. This dataset was used to compare the recent wet and mild years with long historical records and link the variability in streamflow to changes in precipitation and temperature and to compare historical data with the scenarios.

RESULTS

The results of the trend studies presented were performed for the following hydrological variables: annual streamflow (calendar years), seasonal values (winter: December-February; spring: March-May; summer: June-August; autumn: September-November), timing (date of flood peak) and magnitude of floods and summer drought duration and deficit volume (Nordic region) and 30-day minimum flow (Baltic region). For the Nordic countries a rough differentiation of the flood generation mechanism was done by looking at spring and autumn floods separately. The spring flood period was defined to be March 1 to July 15, and the autumn flood period was July 16 to November 11. Timing was defined as the date of the flood peak. For the Baltic countries only spring floods defined as floods occurring between December 1 and June 30 were studied. A more detailed description of the findings can be found in Hisdal *et al.* (2007) for the Nordic countries and Reihan *et al.* (2006) for the Baltic countries.

Annual streamflow

Even if the majority of streamflow series do not show any changes, clear regional patterns are seen depending on the time period analyzed. For a large part of the Nordic region the annual streamflow has increased for the periods 1941-2002 and 1961-2000. Because of some wet, but cold years in the beginning of the 20ies, the trend towards increased annual streamflow disappears for the period 1920-2002. As opposed to the 90ies and beginning of 2000, the 20ies were not only wet but also cold.
For the Baltic region a negative trend in annual stream-flow was found for the period 1922-2003 in the transitional and continental regions. At the same time in the marine regions of Latvia and Estonia a weak positive trend was found. For the period 1941-2003, a positive trend also appears in some parts of the continental regions but the whole of Estonian has a significant positive trend. The shortest period, 1961-2003, is characterized by a positive trend over the Baltic States except southern Lithuania where in most cases no trend was found. It is plausible that the prevailing groundwater feeding and sandy soils cause these differences in trend over the region. These results are in agreement with previous Nordic studies summarized by Hisdal *et al.* (2003).

Seasonal streamflow

For the Nordic and Baltic countries, winter discharge in general shows a significant increase regardless the period studied (Fig. 1). Trends with a 5% significance level are indicated with large black circles (significant positive trend) and large black and white circles (significant negative trend). These are in the following called *significant trends*. Trends that are only significant at a 30% level are indicated with smaller circles, dark grey if a positive and white if a negative trend was found and are in the following called *trends*. Light grey circles indicate that no trend was found. The increase is mainly a result of increased temperature causing more precipitation as rain during the winter. In addition a significant increase in precipitation was found for the Baltic countries. For the longest time period south Lithuania has the weakest positive trend, which is related to the groundwater dominated feeding.

For the spring season a general positive trend for the Nordic countries was observed that could not be seen in the Baltic region. In general, for the periods 1922-2003 and 1941-2003, there is no trend in the spring streamflow in the marine regions or in Estonia. The costal and transitional regions of Latvia and Lithuania have both negative trends and negative significant trends. For the period 1961-2003 a positive trend appears in the regions with lake regulations only. The other regions of the Baltic countries have no trend or a negative trend. A probable explanation for the contrast between the Nordic and Baltic region for the spring season, is the generally warmer climate of the Baltic countries compared to the Nordic countries. Whereas increased temperatures in the Nordic countries lead to a shift in streamflow from summer to spring and winter the shift in the Baltic region is more from spring to winter. Trends in summer flow highly depended on the period analysed whereas in general no trend was found for the autumn season. Hence, there was no consistent pattern over larger regions or between the time periods studied. All changes in summer and autumn streamflow (no changes, positive and negative trends) reflect the tendencies in the precipitation series.

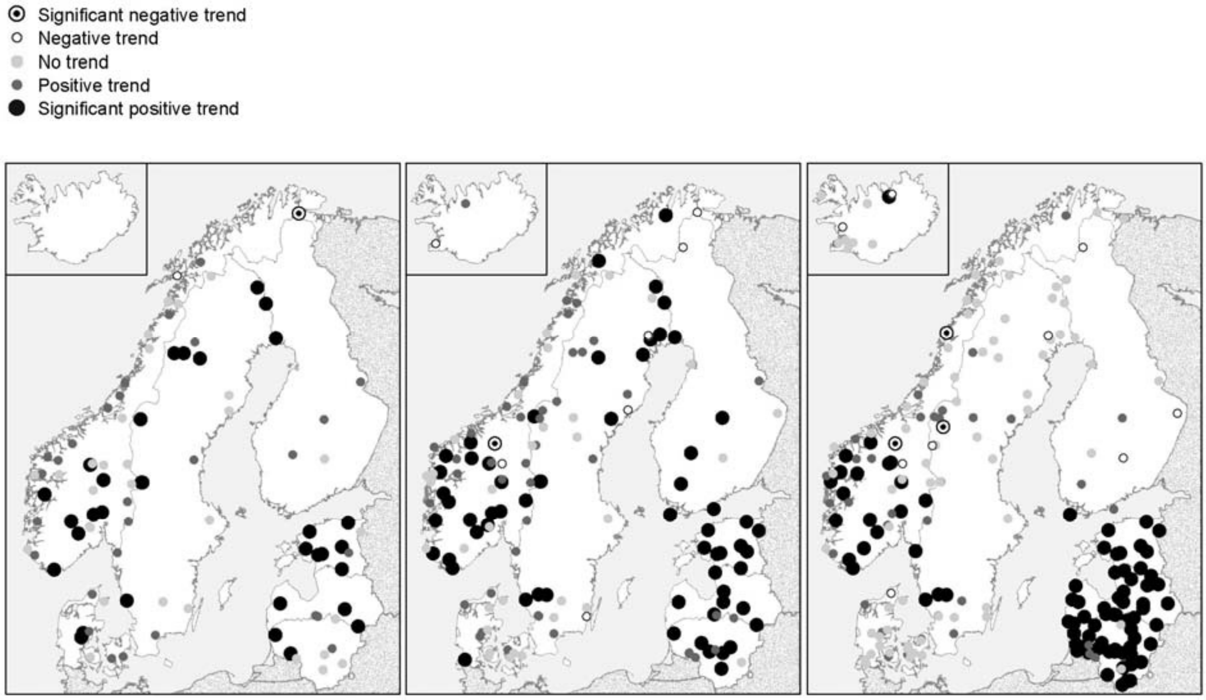

Figure 1 Trends in winter streamflow for the periods 1920-2002/1922-2003 (left), 1941-2002/2003 (middle) and 1961-2000/2003 (right).

Flood and drought

The increased temperature has also caused a trend towards earlier spring floods in many of the catchments and earlier snowmelt floods can be observed over the entire region. Only in Iceland a tendency towards later spring floods can be observed, which is caused by a trend towards lower spring temperatures. It should be noted that also in regions where spring floods are caused by rain only, the floods occur earlier. An explanation for this will require further studies of extreme rainfall events during the spring.

No clear regional patterns were found for spring or autumn flood peak values for the Nordic countries. However, a systematic negative trend in the spring flood peaks in the continental regions of the Baltic countries was found for all periods. The negative trends in spring floods are a result of increased temperatures and decreased snow cover. For the Baltic countries a significant increase in spring temperature and decrease in snow water equivalent, number of days with snow cover and length of the period with a stable snow cover was found.

A trend towards more severe summer droughts was found in the southern part of Norway. For the rest of the Nordic and Baltic regions no systematic pattern in trends was found.

Comparison of trends and expected changes

Long term regional series of temperature, precipitation and runoff were compiled for the Nordic countries. The series represented a total of 24 regions for precipitation and runoff and 17 for temperature. Based on these data, a consistent set of index series for 8 larger regions was developed on monthly, seasonal and annual basis. All series were normalized with reference to the period 1961-1990. Precipitation and runoff were normalized by division by the mean values, whereas temperature was normalized by subtraction with the mean and division by the standard deviation. The regional data provides a possibility to put recent years into perspective and compare both recent years and climate change scenarios with long-term historical observations. Compared to the reference period, the years after 1990 have been mild and wet, both in terms of precipitation and runoff. Annual temperatures were about ½-1 standard deviations above the reference level. All regions and seasons were warmer than in the reference period. Precipitation increased more than runoff in most regions. This could be caused by increased evapotranspiration or be due to data uncertainties. The runoff in 1991-2000 was higher than in the reference period in almost all Nordic regions (Fig. 2 left). The relative increases in runoff were highest in winter and spring. The largest increases occurred in northern Scandinavia. As a summary, the decade 1991-2000 differed from the reference period 1961-90 in the direction of change suggested by the scenarios produced in this project (Fig. 2 right). However, the natural variability is considerable, and temperatures and runoff values similar to those in 1991-2000 have in most regions been experienced earlier, although, not simultaneously. A description of the analysis of regional series can be found in Lindström *et al.* (2006).

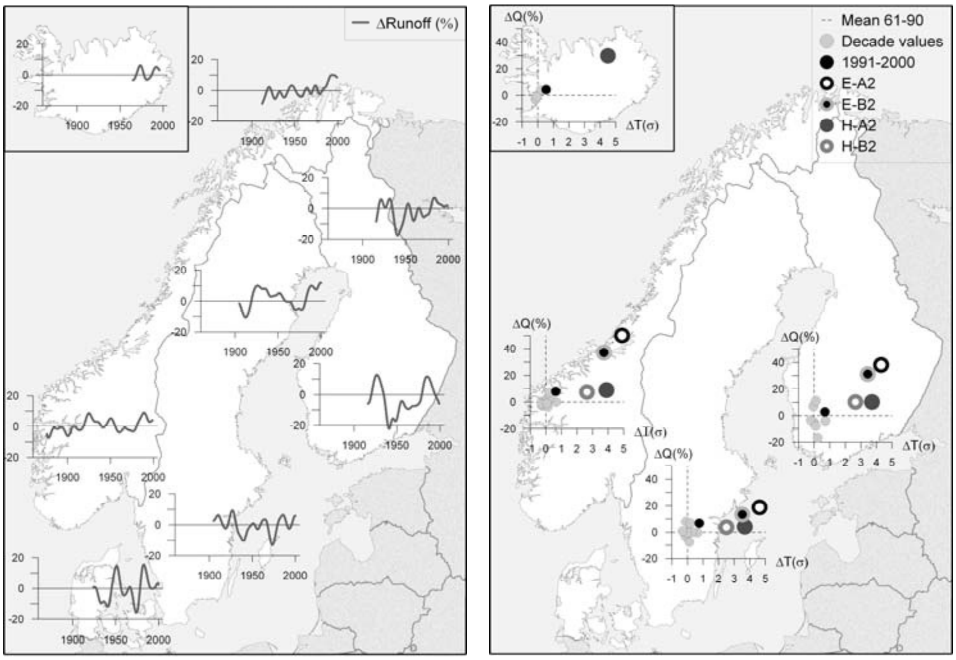

Figure 2 Left: Estimated regional runoff for eight regions relative to the reference period 1961-90 (in %), Gauss-filtered with a standard deviation of three years. Right: Estimated national averages of observed runoff (%) versus temperature (in standard deviations) for decades 1861-2000 (grey dots), mean 1961-90 (lines), and 1991-2000 (black dots). Scenarios for 2071-2100 are shown as larger coloured dots.

The detected trends were also compared to future streamflow scenarios for Norway, Sweden and Finland for the period 2071-2100 estimated by the 'Scenario' and 'Hydrological Models' groups of the CE project (Fenger, 2007). The scenarios generally give an increase in annual, winter, spring and autumn runoff, a reduction in summer runoff, larger rain floods and smaller and earlier snowmelt floods.

CONCLUSIONS

The main objective of the Statistical Analysis group has been to study spatiotemporal changes in historical data. The trends in historical streamflow and climate records from the Nordic and Baltic region show that trends in annual streamflow were governed by changes in precipitation whereas trends in seasonal streamflow and extremes to a larger extent were influenced by changes in temperature. This was also reflected when comparing the regional time series of temperature, precipitation and streamflow. Hence, the observed increase in temperature strongly affects the hydrological regimes in the Nordic countries. This means that if the temperature increase is a result of human induced climate change, the streamflow is changing for the same reason.

A qualitative comparison of the findings of changes in historical data to available streamflow scenarios for the Nordic region, showed that the strongest trends found are coherent with changes expected mainly due to a temperature increase in the scenario period, for example increased winter discharge and earlier snowmelt floods. However, there are also expected changes that are not reflected in the trends, such as the expected increase in autumn discharge and autumn floods. These are changes mainly caused by an expected increase in precipitation.

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A simple model for estimation of climate change induced extreme daily precipitation changes for flash flood modelling

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Keywords: Extreme 5-day precipitation totals, climate change scenarios, rainfall-runoff modelling, flash floods.

ABSTRACT

In order to estimate possible changes in the flash flood regime in the mountainous regions of Slovakia, a simple physically based concept for climate change induced changes in extreme short-term precipitation totals is proposed in the paper. It utilizes regionally downscaled scenarios of the long-term monthly means of air temperature, specific air humidity and precipitation projected for Central Slovakia by three Global Circulation Models (CCCM1997, CCCM2000 and GISS1998). A simplified physically based model for the calculation of short-term precipitation totals at changing air temperatures was proposed, which is used to drive a conceptual rainfall-runoff model. In the paper a case study of this approach in the upper Hron river basin in Central Slovakia is presented. From the 1961-2000 period 26 events of the most extreme basin's average of 5-day precipitation totals were selected. Only events with continual precipitation during 5 days have been considered. These 5-day precipitation totals were modified according to the GCM based scenarios for the future time horizons of 2010, 2030 and 2075. For modelling runoff under the changed short-term precipitation totals the semi-distributed conceptual rainfall-runoff model developed at the Slovak University of Technology was used. Changes in extreme mean daily discharges due to climate change were compared with original floods and discussed.

INTRODUCTION

The incidence of several flash floods in Slovakia over the past decade (Šťastný & Majerčáková 2003) has led to concerns about increase in frequency and intensity of extreme precipitation in relation to increase in the atmospheric water vapour due to global warming. In Slovakia, extreme daily precipitation totals from the 1950-2000 period has been analyzed by Gaál et al (2004) at 557 stations and new design values of K-day precipitation totals for the Slovak territory (K = 1 to 5 days) were developed. Maps of annual maximum K-day precipitation totals with the return periods of 50 and 100 years for Slovakia were prepared and these indicate serious risk of high precipitation totals.

The analysis also showed insignificant dependence of maximum daily precipitation totals on altitude. In spite of this the mountainous areas exhibit more cases of daily precipitation totals above 100 mm than lowland areas. For the future flood risk estimation in mountainous regions, in this study a simplified physically based model for the calculation of short-term precipitation totals at changing air temperatures and humidity was proposed, which was used to drive a conceptual rainfall-runoff model (Lapin and Hlavčová 2003). This approach is presented in the upper Hron river catchment in Central Slovakia, where extreme daily precipitation events with duration of 5-days as representative for the flash flood regime have been selected and analysed.

METHODS

The latest outputs of GCMs scenarios offer monthly values of precipitation variability, specific humidity and air pressure. Precipitation and some other elements are dependent mostly on air temperature, specific air humidity and atmospheric circulation conditions. The scenarios of changes in selected climatic elements in Slovakia have been prepared using model outputs from the Canadian Center for Climatic Studies and Analyses GCMs, issued in 1997 and 2000 and the Goddard Institute for Space Studies GCM, USA, issued in 1998. All GCMs are coupled, i e. atmosphere-ocean circulation models with greenhouse gasses and aerosols influence on change in radiative forcing. Analyses of changes in runoff regime based on these scenarios were published e.g. in Hlavčová et al 1999; Majerčáková 2000; Kostka & Holko 2001; Pekárová & Miklánek 2001 and Petrovič 2000.

Based on regional downscaling of those three models the scenarios of the long-term monthly means of air temperature, specific air humidity and precipitation have been projected for Central Slovakia (only the 2075 time horizon is shown in Table 1 (Lapin et al 2003; Lapin et al 2006)):

Table 1. Deviations of mean monthly air temperature changes (dT) and quotients of mean monthly specific humidity (qs) and precipitation totals (qR) changes according to scenarios based on the CCCM1997, CCCM2000 and GISS1998 outputs for the center of Slovakia in the 2075 time horizon compared to 1951-1980 means

Model	Element	IV	V	VI	VII	VIII	IX	X	XI
CCCM1997	dT[°C]	2.30	2.30	2.90	3.40	3.60	3.60	3.00	2.00
CCCM1997	Qs	1.17	1.17	1.21	1.23	1.23	1.23	1.23	1.21
CCCM1997	qR	1.04	1.07	0.87	0.89	0.94	1.03	1.09	1.18
CCCM2000	dT[°C]	3.80	3.20	2.70	3.50	3.40	3.30	3.00	2.20
CCCM2000	Qs	1.25	1.24	1.20	1.21	1.20	1.20	1.23	1.21
CCCM2000	qR	1.01	1.06	0.88	0.84	0.92	1.11	1.18	1.17
GISS1998	dT[°C]	2.20	1.90	1.80	2.10	2.40	2.30	2.30	2.60
GISS1998	Qs	1.19	1.16	1.13	1.14	1.16	1.15	1.17	1.21
GISS1998	qR	1.07	1.05	0.99	0.97	0.98	1.02	1.05	1.05

The simplified equation for calculation of short-term precipitation totals at changing air temperature (T) was developed by Lapin (Lapin & Melo 2004):

$$R = g^{-1} \int_{to}^{t} \int_{pc}^{0} \omega \frac{ds}{dp} dp.dt, \qquad (1)$$

where g = 9.81 m.s^{-2}, ω = dp/dt = - ρ.g.***w*** – e.g. generalized vertical velocity, ***w*** – vertical component of wind velocity vector, ***s*** – specific air humidity above the condensation level p_c, p – air pressure, t – time, ρ - air density. For the water vapour partial pressure (***e***) and specific humidity (***s***) there is a relation:

$$\boldsymbol{s} = 0.622 \;.\; \boldsymbol{e}/(\mathrm{p} - 0.378\, \boldsymbol{e}). \qquad (2)$$

Dependence of saturated ***s*** (***s****) on **T** at the 900 hPa level is shown in Figure 2. It is supposed that all water falls immediately after condensation as precipitation on the Earth's surface. Decrease in ***s**** at vertical air motion is in accordance with the adiabatic process for saturated air. In the case of rising ***s**** (at higher **T**) also ***w*** is increasing in general, but it depends on vertical temperature gradient and on vertical thermal instability. Supposing increase in turbulent exchange of air humidity and energy at higher **T** by 3-4 °C in the saturated air, the condensation process (and precipitation totals as well) can increase by another 10-50% in the summer season. Final calculation of short-term extreme precipitation totals is based on expected development of monthly **T** and ***s*** averages in the 2010, 2030 and 2075 time frames. For example, at mean ***w*** = 0.1 m.s^{-1} the 24 h precipitation is 35.5 mm for saturated ***s**** = 4 g.kg^{-1} and 174.5 mm for ***s**** = 20 g.kg^{-1} at the 900 hPa level. A graphic expression of this simple precipitation equation (1) is shown in Figure 1.

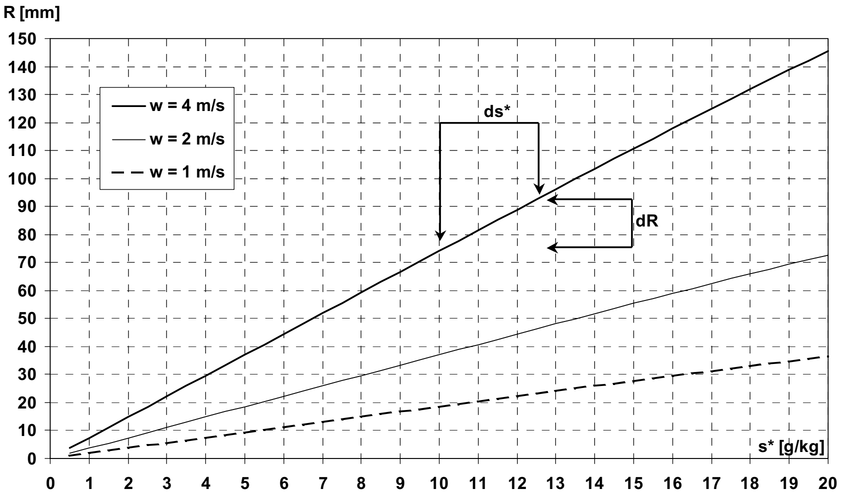

Figure 1. Dependence of 30-minute precipitation totals (***R***) on specific humidity **s*** at the 900 hPa level (considered as a condensation elevation) and on mean vertical velocity (w); values of **ds*** and **dR** show increase in air temperature by 4 °C. Contributions of increased w due to rising air temperature and increased turbulence have to be taken into account (about +30%)

On the basis of this algorithm the 5-day precipitation scenarios (Table 2) can be approximately designed. They follow the **T** and ***s*** outputs of the GCMs assuming that the ***w*** at condensation process will slightly increase with rising **T** and ***s***, mainly in the summer months. Dependence of ***s**** on **T** is shown in Figure 2. Projected increase in precipitation totals for extreme precipitation events is 20-40% for short-term (stormy) totals and 15-30% for 3- to 5-day totals by the 2075 time horizon from April to November.

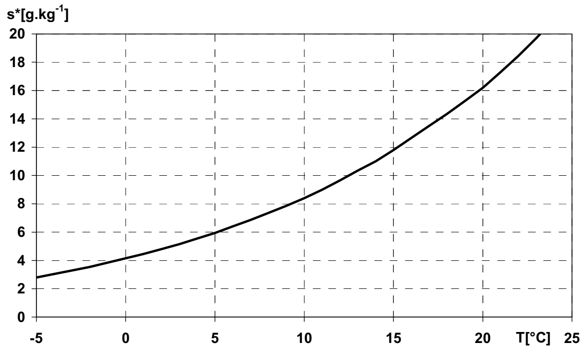

Figure 2. Dependence of specific humidity ***s**** on **T** at 900 hPa level used in equation (1)

Table 2. Quotients of changes in extreme 5-day precipitation totals for three GCM climate change scenarios and horizons of 2010, 2030 and 2075

Model	Horizon	IV	V	VI	VII	VIII	IX	X	XI
CCCM1997	2010	1.07	1.05	1.10	1.13	1.12	1.10	1.10	1.11
	2030	1.11	1.10	1.16	1.20	1.17	1.15	1.13	1.12
	2075	1.25	1.29	1.41	1.47	1.42	1.36	1.28	1.24
CCCM2000	2010	1.18	1.19	1.11	1.15	1.12	1.10	1.09	1.07
	2030	1.25	1.25	1.17	1.24	1.18	1.14	1.12	1.11
	2075	1.38	1.41	1.38	1.47	1.37	1.31	1.28	1.25
GISS1998	2010	1.07	1.08	1.08	1.08	1.06	1.05	1.05	1.05
	2030	1.09	1.11	1.11	1.11	1.08	1.07	1.08	1.10
	2075	1.26	1.25	1.25	1.28	1.28	1.23	1.21	1.25

In the following part of the study 26 events of the most extreme basin's average of 5-day precipitation totals in the Hron river basin were selected from the period of 1961-2000. Only events with continual precipitation during 5 days have been considered. Daily precipitation totals during the selected extreme events were modified according to the supposed changes in extreme 5-day precipitation totals for 3 climate scenarios and the time horizons of 2010, 2030 and 2075. On the basis of assuming dry periods between extreme precipitation events in the future another daily precipitation totals in original data set were not changed. Air temperature and potential evapotranspiration was modified for all the period of 1961-2000 according to the climate scenarios in monthly time step. Changes in potential evapotranspiration [mm/month] in comparison with the reference period of 1961-2000 are illustrated in Table 3 (Lapin & Hlavčová 2003).

Table 3. Changes in potential evapotranspiration [mm/month] for three climate change scenarios and horizons of 2010, 2030 and 2075

Model	Horizon	IV	V	VI	VII	VIII	IX	X	XI
CCCM1997	2010	2.0	2.4	2.1	5.0	7.3	2.8	0.8	1.8
	2030	3.9	3.3	5.5	8.6	9.0	2.5	0.7	1.1
	2075	5.1	11.3	11.5	17.3	16.0	9.1	0.9	2.3
CCCM2000	2010	5.4	8.3	2.7	7.6	8.4	3.3	0.8	1.0
	2030	8.5	8.0	6.5	12.2	10.6	2.5	0.7	1.1
	2075	8.3	15.4	10.8	18.0	14.9	8.3	0.9	2.4
GISS1998	2010	1.8	2.1	2.3	3.8	1.5	0.7	0.4	0.8
	2030	1.5	3.2	3.4	3.7	3.2	1.1	0.4	1.4
	2075	5.1	7.1	6.2	9.6	9.0	7.0	0.5	2.8

For modelling runoff in the Hron river basin the hydrological rainfall-runoff model developed at the Slovak University of Technology was used. It is a semi-distributed conceptual model consisting of three submodels – the submodel for snow melting and snow accumulation, the submodel for water balance in the soil layer and the submodel for runoff generation. The model works in daily time step and contains 15 calibrated parameters. A parameter calibration procedure based on the genetic algorithm using several objective functions is built into the model. Input data required for the runoff simulation in daily time step are basin's average of daily precipitation totals, basin's average of mean daily air temperature and the long-term mean monthly potential evapotranspiration. For the calibration of the model discharges in the basin's outlet are required.

SHORT DESCRIPTION OF THE UPPER HRON RIVER BASIN

The Hron River is a left-side tributary of the Danube River, its basin is located in Central Slovakia. The catchment is feather-shaped, located along the long main river with numerous shorter tributaries. The upper part of the basin with the outlet in Banska Bystrica as a representative for mountainous regions in Slovakia was selected for this study. The basin has an area of 1766 km^2, the minimum elevation of the basin is 340 m a.s.l.; the maximum elevation is 2004 m a.s.l.; and the mean elevation is 850 m a.s.l. Seventy % of the basin area is covered by forest, 10 % by grasslands, 17 % by agricultural land and 3 % by urban areas. The location of the basin within the territory of Slovakia is shown in Figure 3.

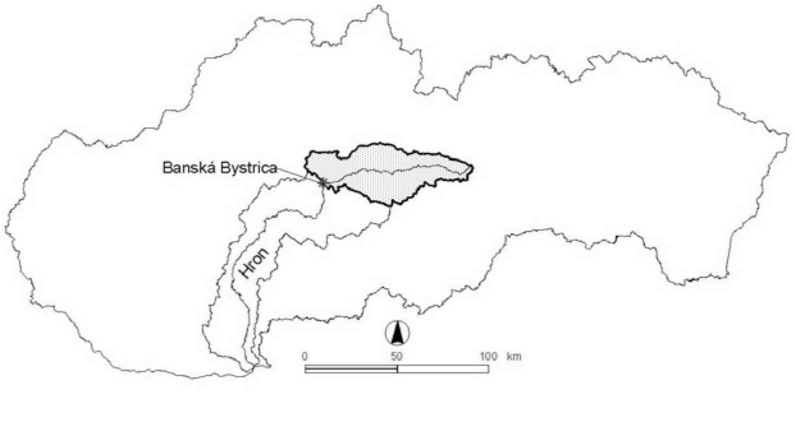

Figure 3. Location of the upper Hron River basin in Slovakia

RESULTS AND CONCLUSION

The rainfall-runoff model was calibrated and validated for the upper part of the Hron river basin on data from the period of 1961-2000. Than for changed climate inputs in all selected 26 extreme precipitation events mean daily discharges using the calibrated rainfall-runoff model were simulated and compared with original floods. From the comparison of original floods with simulated mean daily discharges in the future time horizons a decrease in runoff before and an increase in runoff during extreme situations can be indicated. In many cases increases in mean daily discharges were rather extreme. An example of the comparison between simulated original mean daily discharges (5 days before, 5 days during and 10 days after the selected extreme precipitation event) and simulated floods in the future time horizons of 2010, 2030 and 2075 is shown in Figure 4. Examples of maximum changes in mean daily discharges for 6 selected extreme precipitation events are presented in Table 4.

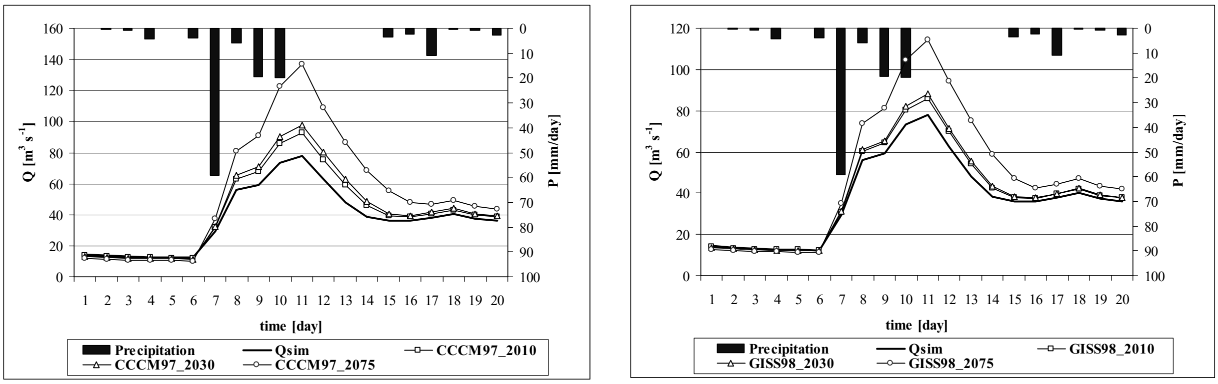

Figure 4. Comparison between simulated original mean daily discharges (Qsim) and simulated floods in the future time horizons of 2010, 2030 and 2075 (for the selected extreme precipitation event in 27.-31.8. 1996)

Table 4 Maximum changes in mean daily discharges in the future time horizons of 2010, 2030 and 2075 according to CCCM1997, CCCM2000 and GISS1998 scenarios (for 6 selected extreme precipitation events)

Date		CCCM1997			CCCM2000			GISS1998		
		2010	2030	2075	2010	2030	2075	2010	2030	2075
21.-25.7. 1976	%	25	36	94	23	36	89	13	17	49
	m^{3}s^{-1}	4.9	7.0	18.2	4.5	7.1	17.3	2.58	3.4	9.7
14.-18.9. 1976	%	16	25	60	15	21	50	10	13	38
	m^{3}s^{-1}	10.0	15.0	34.3	8.8	12.7	30.5	6.3	7.9	23.3
19.-23.5. 1984	%	5	8	32	22	29	50	14	16	27
	m^{3}s^{-1}	6.7	10.8	45.4	31.2	41.9	72.0	19.5	23.3	39.1
21.-25.9. 1984	%	25	42	117	23	34	95	14	18	58
	m^{3}s^{-1}	32.4	51.1	143.7	30.3	41.8	117.2	18.5	24.2	86.5
17.-21.7. 1997	%	16	21	54	14	23	51	9	12	31
	m^{3}s^{-1}	9.1	12.1	29.3	8.2	12.7	27.8	5.3	7.0	17.0
27.-31.8. 1996	%	18.9	25.7	75.9	16.6	24.6	57.8	10.7	13.2	46.8
	m^{3}s^{-1}	14.7	20.0	59.1	12.9	19.2	45.0	8.3	10.3	36.4

From the analysis of changes in the extreme events due to climate change an increase in extreme short-term precipitation and an increase in caused floods can be indicated. From the results of all simulated events it can be seen that the mean daily discharges can increase in comparison with the original runoff up to 70% in the 2010, up to 80% in the 2075 and up to 140% in the 2075 time horizon.

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Climate change and urban flooding in Ho Chi Minh City

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Key words: climate change, sea level rise, land subsidence, urban drainage, heat island effect

ABSTRACT

Flooding in Ho Chi Minh City has emerged as one of the most concerned issues which have arisen in recent years, accompanying the city's rapid growth. The numbers of flooded locations, flooding frequency and duration have increased steadily, resulting in substantial economic and social losses. These phenomena are an integrated consequence of both climate and non-climate related factors.
Over USD one billion has been invested in urban flooding control projects in the city since 1998, with additional billions expected to be spent in the next decades. Long-term planning taking account climate change effects would require non-conventional approaches.
This report is a discussion of several recent studies on unfavorable effects of the uncertainties created by climate change factors on flood control in Ho Chi Minh City.

INTRODUCTION

The area of the studied region is approximately 140 km^2 with ground elevations ranging from +1.0 to +10.0; also, the region is surrounded by a river system. Topographical maps show favorable conditions for the layout of centrifugal directions of sewer with positive slope toward the rivers. During the past century, the urban drainage system was constructed and expanded many times to accommodate the increases in population. Despite 70% of the pipe system put in place is still in good condition, especially, the trunks, it was found that most of them is overloaded as water level in river, rainfall and runoff ratio are increasing with time over the past decades.

Beginning in the 1990s, events of inundation over the city have occurred with increasing frequency. In 2001, a master plan of urban drainage development was financed by ODA of the Japanese government and conducted by PCI (Japan). Since then, many projects totaling more than USD 1 billion have been constructed with funds coming from local authorities and ODA funds. Many of these projects have relieved the inundation problems, despite many new flooding areas occurring during the same time.

Recent studies on the urban flooding problem in Ho Chi Minh City have proven that local climate change, rising water levels, land subsidence and accelerating urbanization are among the most direct causes of the flooding that has caused USD millions in losses damage each year.

A typical project, Tan Hoa-Lo Gom, which consist of several hundreds km conduits of various sizes, both open and closed, in over a catchment of 1500 ha and is subjected to tidal effect at downstream boundary, was chosen to study in detail.

URBAN FLOODING SITUATION

The Urban Drainage Authority of Ho Chi Minh City reported more than 100 serious flooded locations after a heavy rainfall event of 127 mm on May 16, 2004. The same locations are also subjected to inundation frequently even with much lower rainfall intensity. About 20 sites each month are reported as inundated, resulting solely from monthly high tides.

HYDROLOGY

One of the unfavorable factors for urban drainage is the river water level, which is affected by a semi-diurnal tide that usually reaches highest value in September and October. This unfavorable condition is made even worse because the annual tidal peak period is usually coincident with annual rainfall peak's. Data observed and recorded at hydrological stations around Ho Chi Minh City show a remarkable picture of the water level rise since late 1980s (fig. 1). T-Student tests also confirm the difference between means of two sub-series 1960-1989 and 1990-2005 statistically.

Table 1. T-Student test for difference of means of two sub-series 1960-1989 and 1990-2005

Station	TDM	PA	NB	VT	BL	GD	BH
t	2.89	8.60	5.65	3.84	15.48	19.57	20.77
Significance	99%	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%

International researchers in the last decades have overwhelmingly warned about the sea level rise that will occur due to global warming. Further, they continue to indicate that Viet Nam might be one of the most endangered countries, with vast portions of the Mekong Delta and the Ho Chi Minh City areas lying under sea level by the end of this century (Preston et al, 2006; Susmita et al, 2007). Estimates of sea level rise (SLR) were also derived from model simulations associated with the *Third Assessment Report*, and, specifically, the MAGICC simple climate model (v. 4.2).

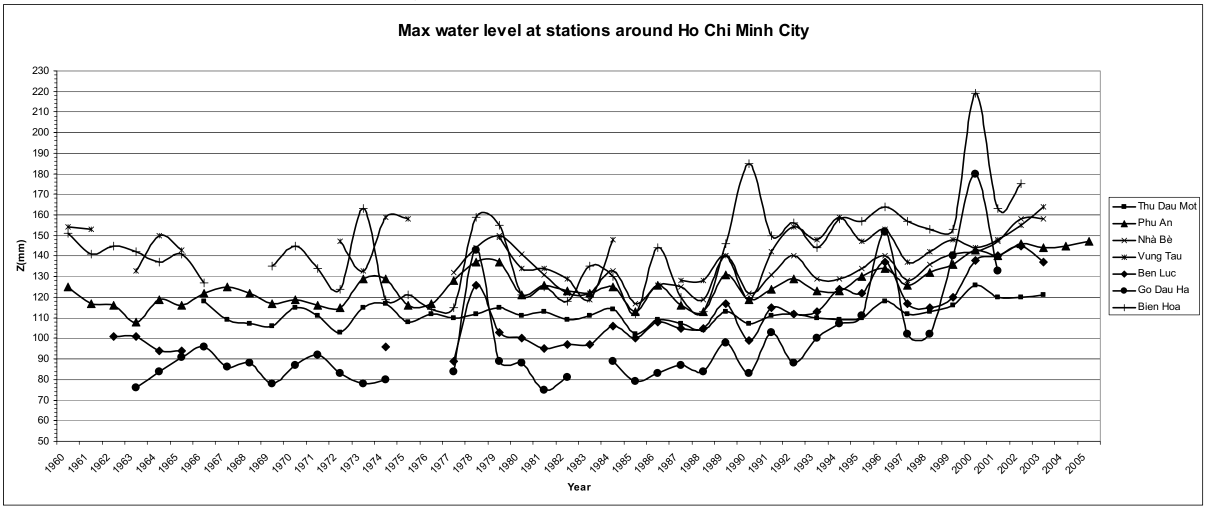

Figure 1. Trend of max water level around Ho Chi Minh City (1960-2006)

The simulations taking account of 6 scenarios of temperature change in the Asia/Pacific region suggest increases in global sea level of 3–16 cm by 2030 and 7–50 cm by 2070 (Preston et al, 2006). Projection using the linear trend of the last 20 years gives an average increase of 1.5 cm per year for the region of Ho Chi Minh City and surroundings. This fact should be included in scenarios for long-term planning of flood mitigation for Ho Chi Minh City.

Simulation tests were conducted for the Tan Hoa-Lo Gom project, which costs about USD 200 million, and was designed according to conventional methods using water level data of the past 40 years. The simulation was conducted by SWMM and applied a projection of 1cm per year in SLR. The simulation calculated flooding duration at 130 nodes of the system and reported nodes that suffered flooding duration larger than 15 min. The result of the simulation shows that in the future, the system might not operate as effectively as has been expected as boundary condition taken in hydraulic design was too low (fig. 2).

HEAVY RAINFALL

Following are some characteristics of heavy rainfall events analyzed from 50-years of data observed and recorded at Tan Son Nhat Station. Statistical data show that heavy rainfall events can occur

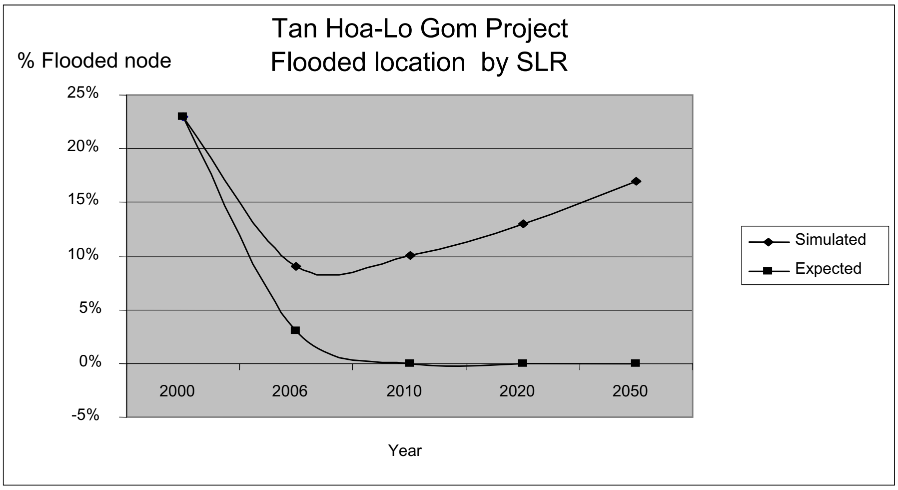

Figure 2. Effect of SLR in Tan Hoa-Lo Gom urban drainage project as simulated

annually from June to October, with yearly “maximum events” occurring most frequently in June, September and October. As mentioned earlier, heavy rainfall events are usually concurrent with periods when the water level is at its annual high. This fact causes an even more severe problem for urban drainage in Ho Chi Minh City.
The fig. 3 shows a linear increasing trend of yearly max 180’-rainfall events as statistically analyzed for the period of 1952-2002. The overall increasing trend of about 0.8mm per year can be explained as being a result of urbanization, which creates favorable conditions for precipitation caused by the Heat Island Effect (HIE).

Heavy rainfall is generally believed to be linked to localized urban warming, which is an unpreventable consequence of urbanization. The compelling evidence for urban-industrial precipitation enhancement was reported from many sources (Sato N. and M. Takahashi, 2000; Dettwiller, J. and S. A. Changnon Jr., 1976).

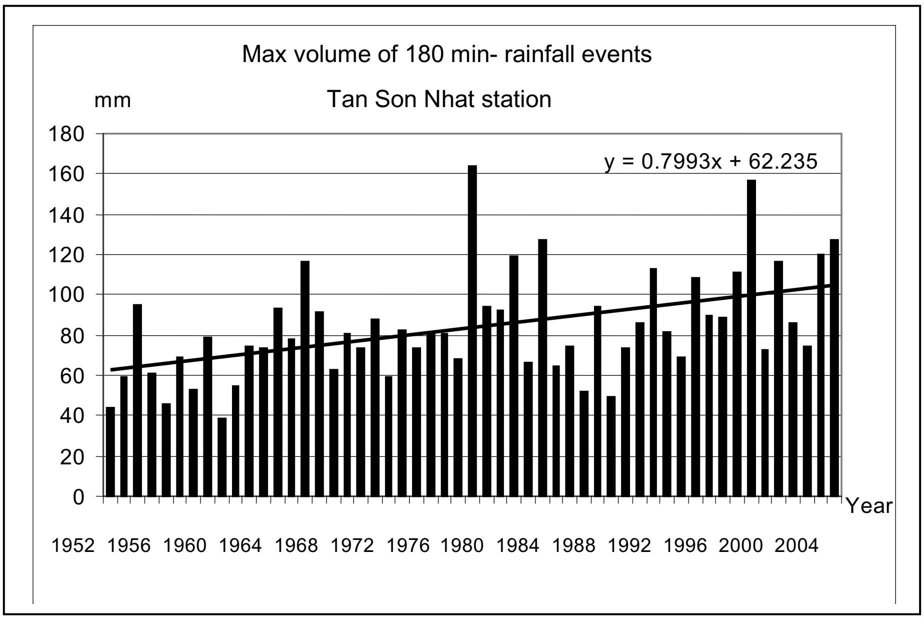

Figure 3. Max volume of 180’-rainfall events (1952-2002)

The increasing rate is as much as 2.45 mm/year in the period of 1988-2004, coincident with the rapid change in urbanization and industrialization occurring in Ho Chi Minh City. The increasing trend is quite similar to that of maximum temperature (Fig. 4).

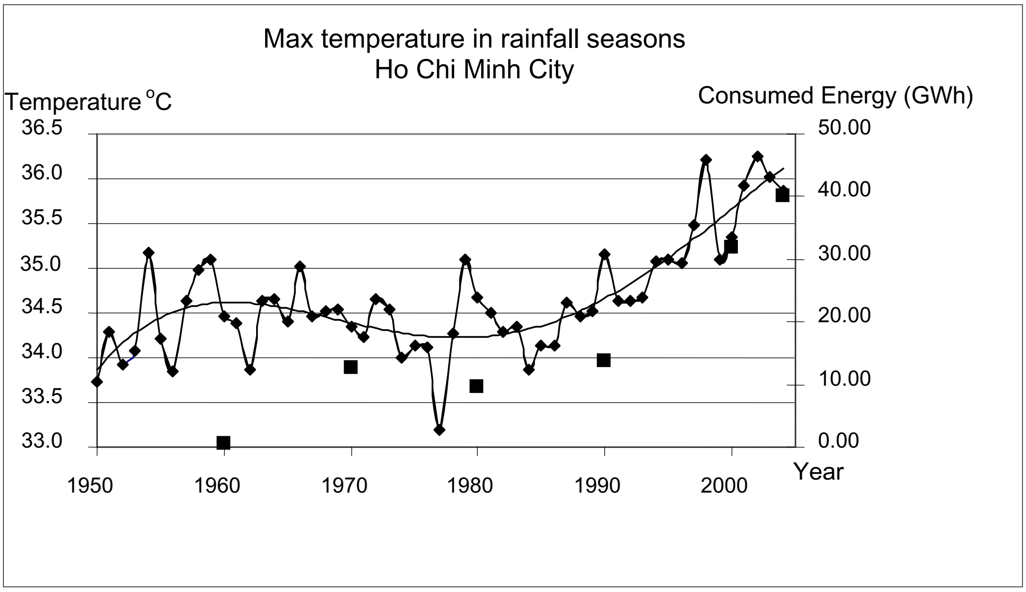

Figure 4. Maximum temperature in rainfall season (square dot) in Ho Chi Minh City vs. energy consumption

In order to confirm the non-stationary property of rainfall series, the Barlett test was conducted. Random noise test using autocorrelation function with 95% confidence limit shows that the yearly max 180'-rainfall events is a non-stationary time sequence.

The evidence in tables 1 and 2 supports the hypothesis of an increasing trend in the occurrence of heavy rainfall events during recent years. The non-stationary time series of the events may make conventional statistical analysis invalid as statistical parameters are changed with time. The fact should be considered in detailed investigations.

Table 1. Counts of heavy rainfall events with various return periods

P =	1 yr	2 yr	3 yr	5 yr	10 yr	20 yr	50 yr	100 yr
1952-1961	9	2	1	0	0	0	0	0
1962-1971	10	5	3	1	0	0	0	0
1972-1981	10	7	4	2	2	1	1	0
1982-1991	10	4	3	2	1	0	0	0
1992-2001	10	8	5	4	1	1	0	0

Table 2 Count of rainfall events with volume >100mm within 180 min

Period	1952-1961	1962-1971	1972-1981	1982-1991	1992-2002
Counts	0	1	2	2	4

Because of the random and independent nature of the occurrences of tide- and rainfall peaks within a long period, the integrated effect of tide and heavy rainfall is actually not simple to determine. It renders inappropriate conventional design methods for storm water sewers that are based solely on analysis of return frequency of rainfall. Study of combination probability as a means to determine repetitive surcharge requires more effort.

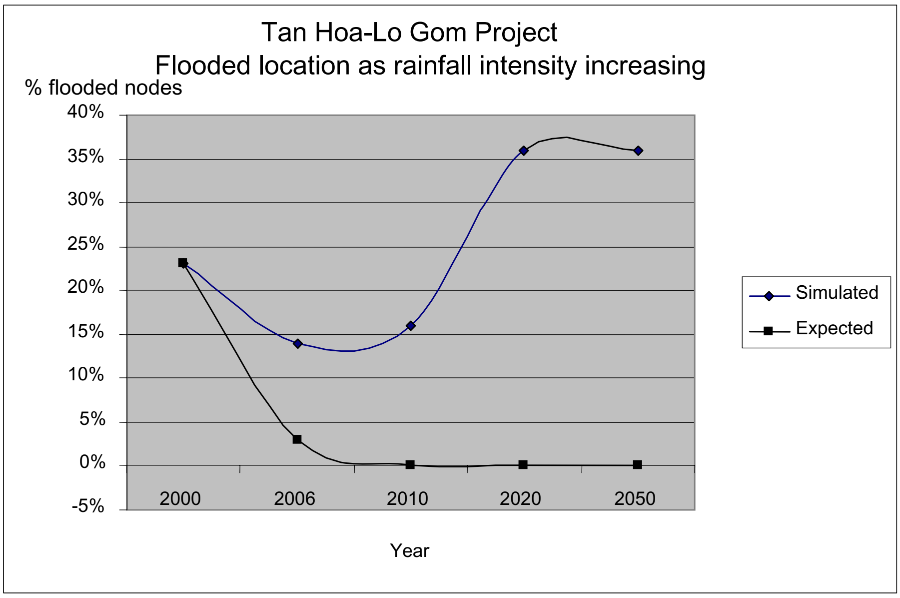

Figure 5. Effect of HIE on Tan Hoa-Lo Gom urban drainage project as simulated

Simulations were conducted to study the behavior of the Tan Hoa-Lo Gom system under scenarios of increasing rainfall intensity of 0.8 mm per year for the 180' events. These simulation were conducted supposing that SLR effect had been eliminated by control construction and water level in rivers would remain as of the year 2000. The effect of rainfall increasing, therefor, can be isolated (fig. 5).

Comparison of figures 4 and 5 shows that unfavorable effect of HIE is even more noticeable than that of SLR. Besides, SLR can be overcome by introducing new water control structures whereas conduits systems that cost USD billions and are being under construction following current technical code can hardly be resized. A promising solution for the problem of HIE may come from water detention techniques.

LAND SUBSIDENCE

Land subsidence has been occurring at a significant rate as observed at some locations in the city. This effect may enhance the flooding situation when combined with rising water levels and more intense rainfall. Similar phenomena were found in Bangkok, Shanghai, Jakarta… and blamed for over-exploitation of groundwater and high-rise buildings.
Many elevation landmarks should be checked and replaced to serve infrastructure construction such as roads and storm water sewers. Some typical subsidence sites are reported in table 3. Land subsidence is creating a similar effect as SLR.

Table 3: Observed subsidence sites in Ho Chi Minh City

No.	Location	District	Ground subsidence (cm)
1	Binh Tien Co.*	6	13
2	Water supply well 1 *	6	5
3	Water supply well 2*	6	6
4	Housing Co. *	6	20
5	Ground water level sensing station*	Binh Tan	14
6	Nam Long Co. *	Binh Tan	14
7	Landmark Q08-056**	8	27,6

Source: *Nguyen van Nga et al, 11/2004 (personal data, unpublished)
* *H. L. Phi and Nguyen van Hanh, 2007 (Survey report, unpublished)

PLANNING AND HYDRAULIC DESIGN FOR THE URBAN DRAINAGE SYSTEM

Due to the natural complexities of the situation, planning and hydraulic design approaches for problems of storm water drainage in areas like Ho Chi Minh City require some problems to be solved:

- Analysis of concurrent probability of tidal effect and rainfall.
- Analysis techniques for non-stationary time series to project future design criteria
- Flexible long term planning to cope technically and economically with the SLR and HIE phenomena.

Many problems are still lying outside conventional design code and should be made clear as soon as possible to introduce scientific bases for design and construction of urban drainage systems in Ho Chi Minh City.

CONCLUSIONS

- Statistical study suggests an increasing trend in water level of about 1.5 cm per year over the last 20 years at Sai Gon River and surroundings. Some scenarios were simulated for a typical project in Ho Chi Minh City, which was found that SLR would reduce effectiveness of conduit system remarkably. The problem is enhanced by land subsidence relating to ground water exploitation and high-rise buildings.
- Hypothesis of increasing trend of heavy rainfall at Ho Chi Minh City for the past 52 years is statistically confirmed with at least 95% confidence limit. The overall linearly increasing rate is estimated as much as 0.8mm per year. This fact agrees with theories of Heat Island Effect on heavy rainfall. The effect of rainfall increasing on capacity of drainage system would be very serious. The problem should be solved by application of water detention techniques.
- Climate change and SLR would result in overload and surcharge of storm sewer systems in the future. Modification of the conventional design code for sewer system to operate under overload conditions in the future requires sophisticated studies including modeling and non-conventional analysis techniques.

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Impact of extreme summer weather conditions on discharge and nitrate N concentrations in small boreal rivers

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Keywords: nutrient export, nitrogen, stream, river, boreal, catchment, extreme events, weather conditions

ABSTRACT

We studied the disharge and nitrate (N/NO_3) concentrations in three small boreal rivers with differing land-use in southern Finland during contrasting summer weather conditions. We focused on a very dry summer 2003 and the following extremely wet summer 2004.

In summer 2003 discharge in three rivers and N/NO_3 concentrations in two rivers were low in comparison to the long-term averages. Discharge responded rapidly to increased precipitation, being e.g., 2.7- times higher in late July-early August 2004 than on average (1994-2004) in R. Mustajoki. N/NO_3 concentrations were also clearly higher following the extreme precipitation events than on average. N/NO_3 concentrations increased most relative to the 11-year average in a small subcatchment Koiransuolenoja with higher proportion of agriculture and especially sugar-beet cultivation.

The results show that during the base flow the concentrations of N/NO_3 remained rather stable. Intensive precipitation events modify the hydrology and nutrient concentrations and thus also the loads in small boreal rivers which, depending on the timing of the event, is also likely to affect the ecosystem of the recipient lakes.

INTRODUCTION

Nutrient loading from the catchments is generally strongly related to seasonal and annual climatic and hydrological variation, and land-use. Recent climate scenarios suggest for northern Europe increases in air temperature during the summer seasons and in precipitation during the winter as well as higher frequency of extreme weather events (e.g. Jylhä et al. 2004).Changes in weather are likely to modify the timing and magnitude of discharge and nutrient loads from the catchments in the future (e.g. Andersen et al. 2006). In this study we compare discharge and nitrate loading during two consecutive summer seasons with contrasting weather conditions in 2003 and 2004 in three small rivers, all situating close to each other in southern Finland. The three catchment areas differ in terms of land-use and hydrological characteristics.

MATERIAL AND METHODS

The studied subcatchments belong to the drainage area of Lake Pääjärvi (Fig.1.) with a total area of 223 km^2. Land-use is dominated by forests, agriculture and peatlands (Table 1), and there is no point-source pollution in the study area. Forests are typical coniferous Taiga forests dominated by the Norwegian spruce and the Scots pine with deciduous trees birch, aspen and alder. The area lies between 103 m and 180 m a.s.l.

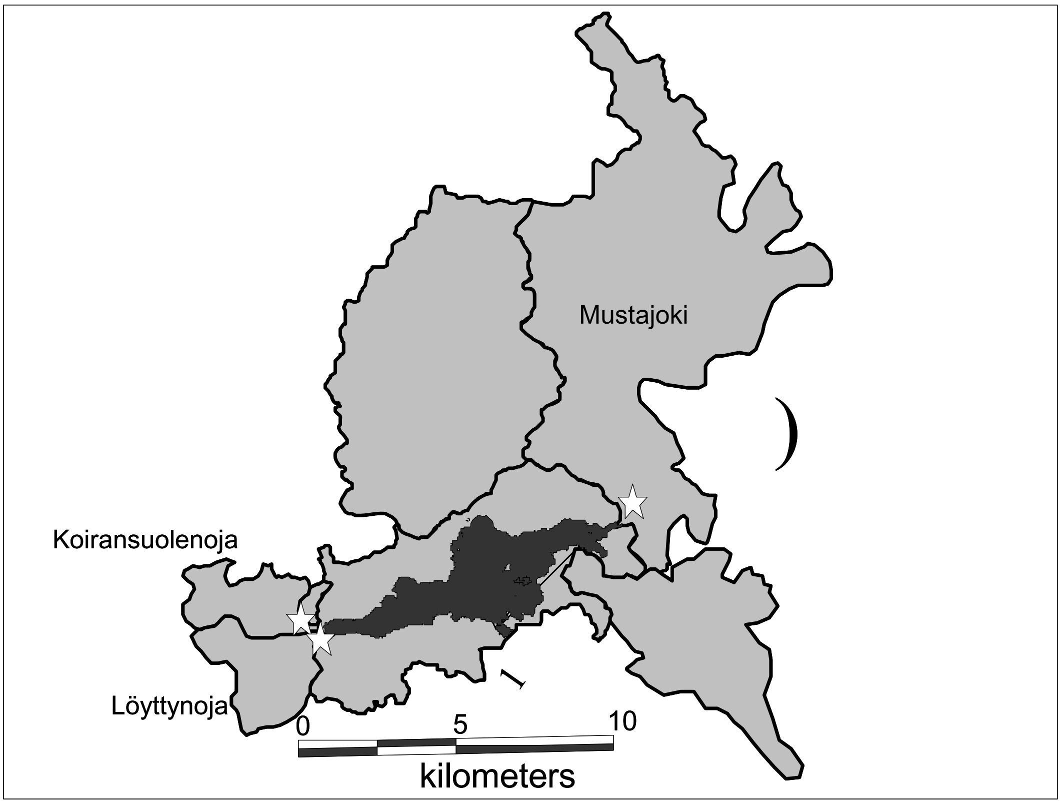


Figure 1. Map over the study catchments. The symbols indicate the three sampling points. Lake Pääjärvi presented in dark grey.

Table 1. The area and land-use of the studied catchments

	Musta-joki	Löyttyn-oja	Koiransuolen-oja
Area (km^2)	76.3	7.8	6.2
Agriculture (%)	13	17	24
Peatlands (%)	20	14	5
Forest (%)	67	69	71
Lakes (%)	0.3	0	0

The weekly N/NO_3 data was available from a 11 year period (1994-2004). Daily discharge measurements covering the same period was available for R. Mustajoki. The runoff values derived from the discharge were used for all the three subcatchments. The discharge measurements were carried out by the Finnish Environment Institute (SYKE).

The mean (1994 - 2004) annual precipitation in the study area is 621 mm, and on average 38%, i.e. 227 mm occurs during the summer months (June-August). During the 11 years period, summer 2004 was clearly the wettest, the precipitation being 413 mm, and summer 2003 was relatively dry (189 mm) and it followed the very dry year 2002 (annual precipitation 535 mm).

RESULTS

There was a remarkable increase in the discharge during the summer of high precipitation (Fig.2.). The peak discharges were observed one to four days after the peaks in precipitation. In summer 2004 the average runoff for R. Mustajoki was 14.7 L s^{-1} km^{-2} when the average summer runoff in 1994-2004 was 5.5 L s^{-1} km^{-2}. In summer 2003 the runoff was 1.8 L s^{-1} km^{2}, the second lowest in the 11 year period.

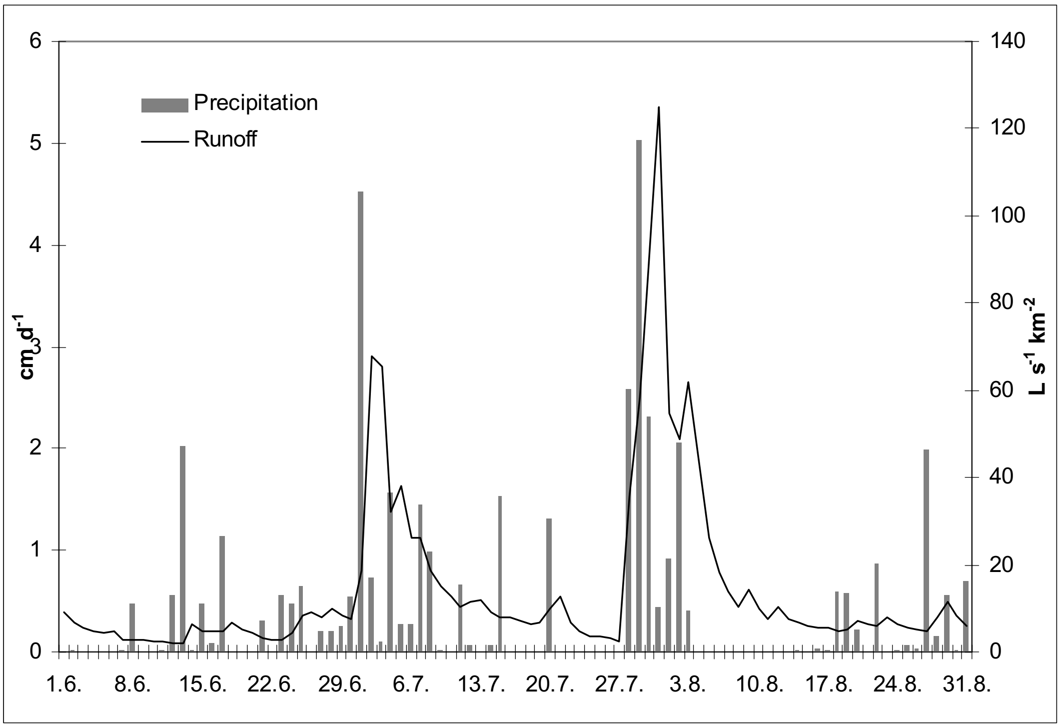
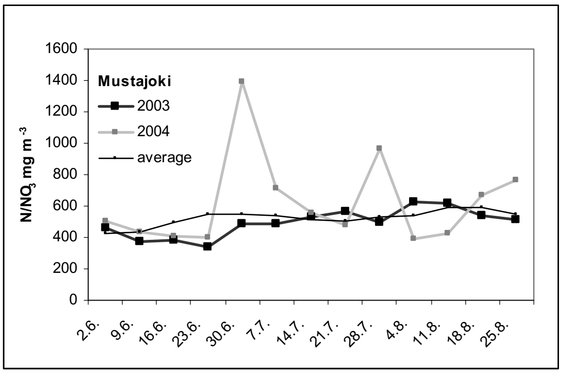
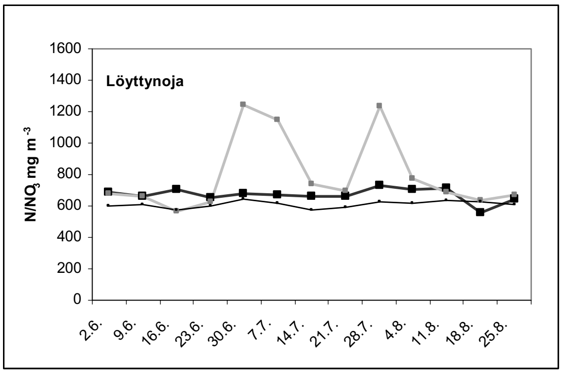


Figure 2. Precipitation and runoff during summer 2004.

The average weekly N/NO$_3$ concentrations for the period 1994-2004 were rather uniform throughout the summer. During the wet summer of 2004, the maximum concentrations of N/NO$_3$ were clearly higher than the average in all rivers (Fig.3). N/NO$_3$ concentrations increased most strongly in R. Koiransuolenoja, the subcatchment with more intensive agriculture. In 2003 the concentrations were below the long-term average in rivers Mustajoki and Koiransuolenoja, but in R. Löyttynoja, the concentrations remained higher than the average also during the dry summer. The reason for high concentrations in R. Löyttynoja is not yet clear but it is certainly connected to the increasing trend in the N/NO$_3$ concentrations in the river during the observation period.





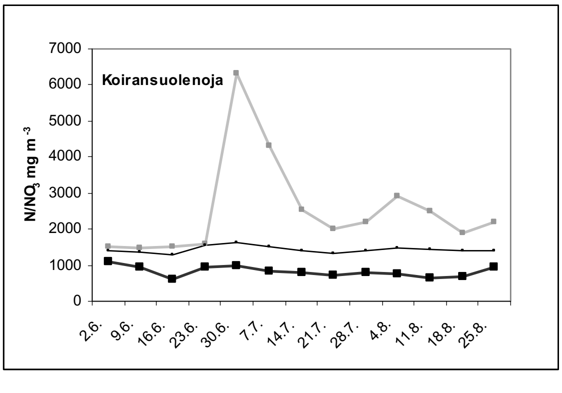


Figure 3. N/NO$_3$ concentrations during the summers 2003 and 2004 compared to the average of years 1994-2004. Note the differences in y-scale.

The average loads for summers 1994-2004 were 23 kg N/NO$_3$ km^{-2} for Mustajoki, 27 kg N/NO$_3$ km^{-2} for Löyttynoja and 63 kg N/NO$_3$ km^{-2} for Koiransuolenoja. In dry summer 2003 the loads were around one third of the average: 6.5, 9.7 and 12.9 kg N/NO$_3$ km^{-2}, repectively. Due to the high runoff and elevated concentrations during the summer 2004, there were remarkable increases in N/NO$_3$ loads in all three study rivers (Fig.4.).

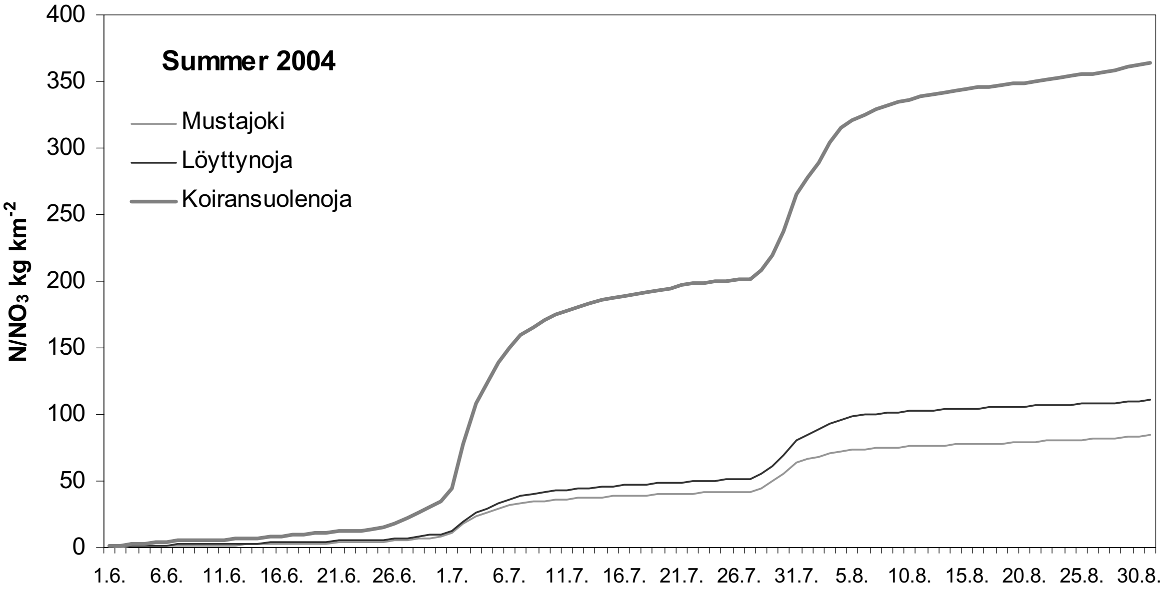


Figure 4. Cumulative N/NO$_3$ loads for the studied rivers during the summer 2004.

DISCUSSION AND CONCLUSIONS

The N/NO$_3$ loads in summer with high precipitation comprised an outstanding proportion of annual loads: the summer 2004 loads were 41 % of R. Mustajoki, 64 % of R. Löyttynoja and 88 % for R. Koiransuolenoja of annual annual average N/NO$_3$ loads (1994-2004), respectively.
This implies heavy loading into the recipient lake in the middle of the growing season, exactly at the time when algae usually suffer from shortage of nutrients. Normally most of the nutrient losses have been observed to occur in spring, autumn, or early winter in connection with low intensities of biogeochemical processes (e.g. Rekolainen et al. 1995).
Arvola et al. (2006) found high and statistically significant correlations between discharge and inorganic and total nutrients during the summer-autumn period (June-November) in their eight-year study of three rivers draining to Pääjärvi, including also rivers Mustajoki and Löyttynoja. Their conclusion was that climate is a key driver regulating both seasonal and annual nutrient loads from these boreal upstream rivers. Here we show that higher frequency of extreme weather conditions in the future will probably add variation into timing and magnitude of nutrient loads from the catchments.

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Adapting Watersheds to Climate Change and Variability in West Africa. The case of Offin River basin in Ghana

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ABSTRACT

Climate change and its potential impact remains a fundamental issue for sustainable development in the next decades in Africa. In developing nations, where per capita demand for natural resources is fast rising due to several reasons, the need to develop and mainstream adaptation measures into national development strategies, particularly for economies that depends almost entirely on natural resources for economic growth and sustainability is imperative. The Offin watershed located in Ashanti region of central Ghana have for decades played critical role in livelihood sustainability both for urban and rural communities. The provision of water resources (portable water, fresh fish etc) for consumption even to large cities, recreational activities, navigation and manufacturing are just a few of these functions. There is also the provision of other forest goods and services for the short term wellbeing of the communities around the watershed. Recent observations reveal a decreasing rainfall amount with a skewed distribution pattern, increased temperature and rapid destruction of the riparian forest around the watershed, resulting in considerably alteration in ecosystem functions in the past three decades. The region's economic future will therefore depend on how well the ecological system and the ecosystem functions of the watershed are adapted or respond to potential threats from climate change impact. The degree of vulnerability of the watershed and its dependent communities to climate change and variability is not clearly understood. How it's the ecological systems will be altered has not been studied and documented, making it difficult to propose any future adaptation strategies. Hence, the primary goal of this study was to contribute to the processes of adaptation to climate change through the assessment of vulnerability of the watersheds and its dependent communities. This paper examines rainfall and temperature patterns in the River Offin basin and assesses the vulnerability and adaptation options of the River Offin basin to climate change and variability.

INTRODUCTION

Sub-Saharan Africa and West Africa in particular have experienced severe effects of unstable climate over the past decades. In the 1970s, mean annual rainfall decreased by 10% in the Wet Tropical Zone to more than 30% in the Sahelian Zone, meanwhile the average discharge of the region's major river systems dropped by 40 to 60% (Niasse, 2005).

Even though Africa has least contributed to the Green House Gas emissions (WDM, 2007), she is presumably the most vulnerable to impacts of climate change. This is because Africa lacks the economic and social resources to adapt to the long term effects of climate change (IPCC, 2001). Africa's problems of high population growth rate, wars, famine, debt and diseases, could further be compounded by the impacts of climate change. According to World Development Movement (2007) 160 million people are already dying every year from climate change related diseases and billions will face drought, floods, starvation and diseases in the coming years. The Third Assessment Report of IPCC observes that 'scarce water resources are becoming increasingly critical for Africa; they determine food security as well as human and ecosystem health, and play a major role in political and socioeconomic development'.

Climate change and variability are no longer issues for the future since the effects are already being felt in Ghana. Opoku-Ankomah and Amisigo (1998), through the evaluation of 40 years of rainfall and runoff records, concluded that there has been a significant reduction in rainfall and runoff in South-western Ghana, and linked that to the influence of climate change. River basins in Ghana are expected to experience marginal vulnerability by the years 2020 and 2050 (1st Ghana National Communication 2001), resulting in secondary impacts on health, nutrition and energy-based industrial activities, if proper adaptation options are not put in place.

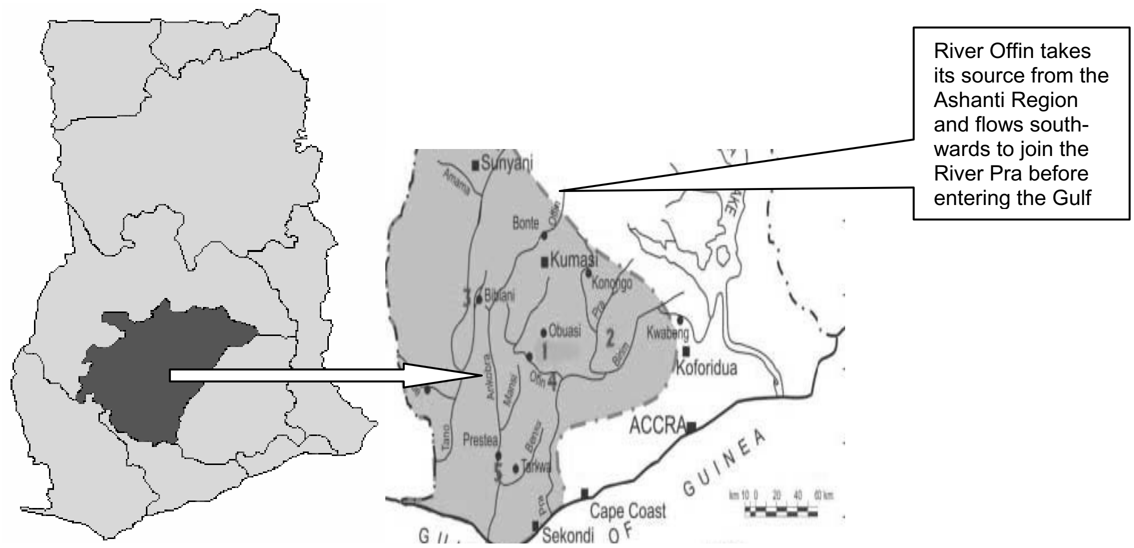
Ghana started experiencing severe energy crises since 1998 but lingers to date partly due to a reduction of volume of water in the River Volta. Though several reasons have been proffered for the reduction in water volume in the Volta Lake, recent studies have however linked this to climate change and variability (Andah, 2003). Almost a decade afterwards, further reduction in water volume has exacerbated a national crisis in the energy sector resulting in electricity outage and rationing throughout the country. This has affected the country socially and economically, with the closure of major industries. The Third Assessment Report of IPCC observes that ‘scarce water resources are becoming increasingly critical for Africa. Climate change therefore, poses great danger to water availability for sustainable livelihoods in the region. Especially with changes in rainfall patterns and increased temperature, the discharge of many rivers, drinking water supplies, and irrigation practices may be affected. This will in turn affect food security and income levels of many watershed-dependent communities.

This paper therefore, examines rainfall and temperature patterns in the River Offin basin and assesses the vulnerability and adaptation options of the River Offin basin and its dependent communities to climate change and variability.

MATERIALS AND METHODS

Site description

Ghana lies on geographic coordinates 8°00′N, 2°00′W, on the coast of the Gulf of Guinea in West Africa with a total land area of 238,540 km² and a humid tropical climate. The River Offin watershed is found in the Ashanti region of central Ghana. Most communities in the River Offin basin are rural and predominantly farmers who depend on the river for their livelihoods. The Offin river basin provides 80% (18 million gallons) of potable water daily to the Kumasi metropolis from the Barekese reservoir, water for irrigation of farms, source of fish for the communities, transportation of humans and farm produce, water for other domestic and industrial activities. It also provides timber and other forest products such as fuelwood, game, medicinal plants, and also recreation Deforestation rate was 2% between the years 2000 and 2005 (FAO, 2007)



River Offin takes its source from the Ashanti Region and flows southwards to join the River Pra before entering the Gulf

🟥 **Ashanti region of Ghana**

Data Collection and Analysis

The first stage of the work analysed the climate situation in the Offin river basin to establish a trend. The intention is in trying to use past baseline climate to understand the future, and to avoid the uncertainties involved in regional climate predictions. Forty-six (46) years of historical rainfall and temperature data were collected from the Ghana Meteorological Agency offices in Kumasi. Temperature and rainfall data were used because they are the climate variables that are likely to reveal changes in extreme values during the period of study.

The annual maximum and minimum temperatures and precipitation over the period of 1961-2006 were analysed to establish historical trends using linear regression equation. The seasonal and inter-annual variability was also assessed.

With CRISTAL 3.0 (**C**ommunity-based **Ri**sk **S**creening **T**ool - **A**daptation & **L**ivelihoods), developed by IISD, IUCN, SEI-B and Intercooperation as a guide, interviews, questionnaires, focus group discussions and literature search were used to set the climate and livelihoods contexts of the communities in the River Offin basin. The CRISTAL 3.0 has two modules and the module 1 which is used for synthesizing Information on Climate and Livelihoods was used.

The synthesizing is done in two ways; setting the climate context and setting the livelihoods context. In setting the climate context, the current climate hazards and the impacts of the hazards and climate change in the River Offin basin; particularly on local livelihoods were identified. Secondly, the livelihoods context set by identifying the natural, physical, social, financial, and human resources of communities in the Offin river basin were identified. The extents to which these resources help the people to conduct their livelihoods and cope with these impacts were assessed. This formed the baseline for the vulnerability of the communities to potential climate change and variability.

River height measurements on the River Offin at Adiembra station (downstream) and Offinso station (upstream) from 1957 to 2006 were collected from the Hydrological Agency of Ghana office in Kumasi. River discharge measurements of the River Offin at the Adiembra station from 2002 to 2006 were used to construct a rating curve for the Offin River. From this curve, a rating equation was generated and used to estimate the discharge of the river at the recorded river heights from 1957 to 2006. From this data, the trend in discharge of the River Offin over the last forty years was established.

RESULTS

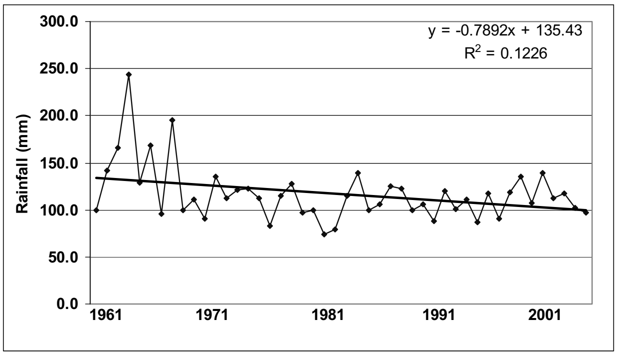
Mean Precipitation in River Offin Basin

The time series analysis of rainfall data highlights some features that represent the hydroclimatological changes over the basin within the last 4 decades (Figure 1). There was a remarkable reduction in the mean annual precipitation recorded over the period of 1961 to 2006. Mean annual precipitation decreased by 22.2% from the 1960s to the 2000s, corresponding to mean annual rainfall amount of 144.8mm in 1961-1970 and 112.7mm in 2006.

Considerable variability in total annual rainfall in four and a half decades with sharp decreases in mean (≤1200mm) between 1985 and 2000 were observed. Total mean annual rainfall of 1367.5mm was recorded from 1961 to 2006.

The two decades of 1981-2000 recorded the least mean annual precipitation (105.9 mm) in the period under study and the highest mean annual precipitation (144.8 mm) was recorded in the decade of 1961-1970.

Though, the seasonal trend did not change much over the years; however, a main peak in May to June and a trough in July to August and a secondary peak September to October (Figure 2) was observed, this reflects the 2 rainy peaks in the region and the depression in August illustrating the little dry season or August break.



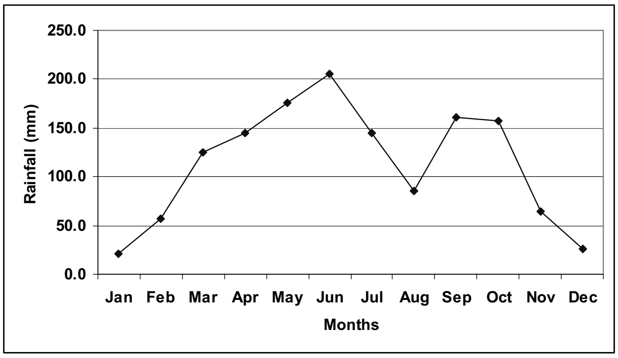


Fig. 1.Trends in Annual Rainfall in River Offin Basin (1961-2006)

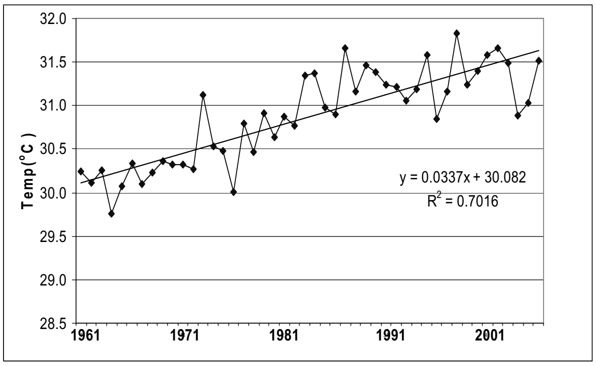
Fig. 2. Mean monthly rainfall for River Offin basin (1961-2006)

Mean Maximum and Minimum Air Temperatures

The time series analysis of annual temperature indices indicates that changes in temperature extremes during the period of investigation reflect warming.

The general trend of mean maximum and minimum temperature recorded over the period 1961 to 2006 is presented in Figures 3 and 4 respectively. Figure 3 shows a gradual rise in average maximum temperatures over the stated period from 30.2 °C in 1961 to 31.5 °C in 2006, indicating a 1.3°C or 4.3% rise in temperature. The mean minimum air temperature (Figure 4) followed a similar trend, starting with an annual mean of 21.1 °C in 1961, to 22.1 °C in 2006. This is a 1.0 °C (4.7%) rise over the entire period, compared to the 1.3 °C (4.3%) rise in mean maximum air temperature over the same period.

Over the four and a half decades, mean maximum temperatures have been quite varied. However, there has been a gradual and consistent rise in temperatures. From a mean maximum temperature of 30.2 °C in the first decade of 1961 – 1970, the mean maximum temperature for 2001 – 2006 is 31.4 °C. 1998 and 1964 are the warmest and coldest years, respectively, in the last forty-six (46) years.



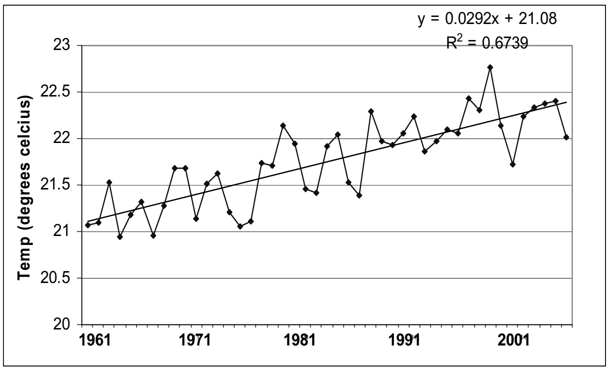


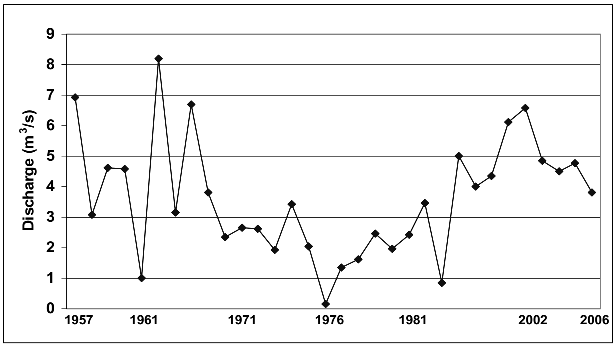
Fig. 3. Trends in Mean Maximum Air Temp.. (1961 2006)

Fig. 4. Trends in Mean minimum Air Temp. (1961-2006)

Discharge of River Offin

From 1957 to 2006, discharge of River Offin has varied over the years (Figure 5), with the highest discharge of 8.177m^3/s recorded in 1963 and the lowest discharge of 0.139m^3/s in 1976. Generally, from 6.941 m^3/s of discharge in 1957, the discharge of River Offin at 2006 was 3.797m^3/s indicating a 3.144 m^3/s (45.3%) reduction in river discharge or flow rate.

Mean monthly discharge followed a similar bimodal pattern as the mean monthly rainfall, with two peaks in June and October. Unlike the rainfall, the major and minor peaks for discharge occurred in October and June, respectively.



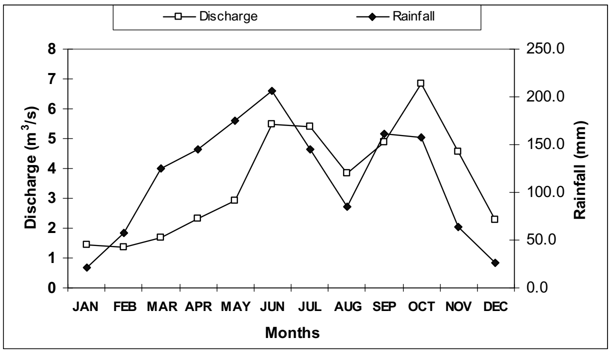


Fig. 5. Mean Annual Discharge of River Offin (1957-2006)
Fig. 6. Mean Monthly Discharge and Rainfall for River Offin (1957-2006)

Vulnerability of River Offin Basin to Climate Change and Variability

The Climate and Livelihoods Context

The communities identified three main climate-related hazards, affecting them currently, as prolonged inadequate rainfalls, drought and extreme heat. They also identified the following as their important livelihood resources:

Natural Resources - Forest products, River Offin and Land
Human resources - Indigenous knowledge, agricultural skills/training, water management skills/training
Financial Resources - Remittances, Savings
Physical Resources - Wells, bridges, roads
Social Resources - Local Community based organizations, Local Governance Institutions

As predominantly poor farming communities and majority not having access to pipe water, the identified resources are very crucial to their survival. They mainly depend on the Offin river and streams in the basin for their water needs both for domestic purposes and irrigation. Some regularly fish in the River Offin. The forest also provides game and other forest products for the community, with some earning all their income from trading in non-timber forest products such as snails, mushrooms, pestles, etc.

The people believe that prolonged inadequate rainfalls is a major climate hazard because it affects the quantity of water in their streams and their crops do not also do well without the rains. According to the communities, some of the streams which use to be perennial, now only flow during the rainy season. The River Offin was reported to have divided into two during the dry season of 2006 making water very scarce in the communities. Wells that were constructed to help provide quality water for the communities completely dried up in during the dry season. Though most of the people indicated their preference for water from the river Offin because, according to them, the well water does not taste good. Also in the dry season, the quality of water in river Offin deteriorates and cases of bilharzia are often reported. Whereas many people perceive the effects of prolonged inadequate rainfalls to fully impact the communities, effects of extreme heat is also being felt. Heat related diseases such as shingles, malaria and other skin diseases are observed to be common in the community.

Admission of future threat to their sources of livelihood with current climate trends was unanimous with current trends. There are already attempts by the communities to adapt to the current climate changes, even though they may not directly link it to response to climate change Existing traditional coping strategies by the people include rainwater harvesting, protection of the water sources (Community taboos and laws) and waiting for the rains to set in for sometime before planting to prevent crop failure. Despite these coping strategies already in existence, the communities strongly believe that "finance" is the answer to effects of climate change at community level.

DISCUSSION

Climatic and Hydrological Characteristics of the River Offin Basin

The decline in precipitation in the River Offin basin is very much expected since dry conditions have prevailed in most parts of West Africa since the late 1960s. According to Nicholson (1999), rainfall between 1968 and 1997 has been on average some 15%–40% lower than during the period 1931–60.Mean annual precipitation in the Offin basin has decreased by 22.2% from 1960 to 2006 and this agrees with Niasse, (2005) assertion that In West Africa, there has been significant decline in rainfall since the 1968-1972 periods, from 15 to 30% depending on the area. This further buttressed the general assertion that climate change is already having a gradual negative influence in the region.
Air temperature in the River Offin basin has increased by 1.0-1.3 °C between 1961 and 2006. Deforestation in the Offin basin is high, as in other parts of Ghana. Conversion of forested areas into other uses has been identified as a contributing factor to climate change, accounting for 33 percent of the increase in atmospheric CO2 since 1850 (de Sherbinin, 2002).

Because water budgets of forest ecosystems are heavily dependent on climate and forest structure, increasing air temperature, coupled with reduced rainfall could increase the evaporative demands of forest ecosystem. Deforestation could also lead to water loss, this combined with high temperature and reduced rainfall may have affected flow/discharge of River Offin from 6.941 m^3/s in 1957 to 3.797m^3/s in 2006, indicating a 3.144 m^3/s (45.3%) reduction. At this rate, the River Offin may dry up in the coming years. The extinction of the river will have many consequences for the dependent communities, most of whose livelihoods are centred on the Offin River basin.

Impacts of climate hazards and coping strategies in the River Offin basin

Droughts results in water shortages, food insecurity, reduced water quality, and bush fires. As the climate changes, there is reason to believe that drought hazards will increase (Downing and Ludeke, 2002). In the late seventies and early eighties, severe droughts and the accompanying bush fires destroyed forests and farms, resulting in crop failure, livestock losses, malnutrition, increased health risks and famine.

During the years of prolonged rainfall deficits in the region, water shortages lead to crop damage/loss and loss of income to the people in the community. This is because the communities depend on the Offin River for their water needs although there are a few wells in some of the communities. Most of these wells also completely dry up during the dry seasons. The River Offin stagnates and gathers in pockets along the river course during the dry season, it is turbid and insect larvae are at times found in the water. As a result water related diseases such as Bilharzia, diarrhoea and malaria are common at this time (Nsiah-Gyabaah, 2001). The main impact of extreme heat on the people is diseases such as shingles, heat rashes and malaria. This brings an extra cost in terms of medication as a coping strategy, on the relatively poor communities.

To cope with water shortages, the communities resorted to water rationing (example, the use of water used for washing cloths for backyard gardens, reduction of water use per day) and rain water harvesting as coping strategy. The traditional and local authorities have started realizing the impacts of felling of trees along the river banks on the streams/rivers and are making attempts to remedy the situation through awareness campaign on the effects of deforestation around water bodies, sensitization of community to reduce bush fires, community base management of the forest etc.

Influence of Climate Hazards on Important Livelihood Resources

Eriksen (2001) predicted that 'given the potentially dramatic effects on local climate, natural resources, infrastructure and economic activities, Africa may be particularly physically vulnerable to and at risk from climate change'. Prolonged rainfall shortages and droughts cause a reduction in the volume of water available to the community and crop failure. Due to crop failure/loss, money spent on land preparation and planting, as well as income from the sale of farm produce is lost and household savings are spent to replant farms.

Bushfires are common during droughts and occur annually in the dry season, usually from November to March, during land preparation in anticipation of the first rains, for planting. Large tracts of farms and forests are burnt during such fires. Records indicate that only 20% of the forest zone in Ghana is currently covered by forest which has not burnt regularly (Hawthorne, 1994).

Tropical or heat related diseases such as malaria, shingles and skin rashes are increasing in the communities due to the increasing ambient temperatures. Extreme Heat has very significant influence on the financial resources of the communities as money is spent on the treatment of diseases. The human resources are also affected as pupils, teachers, and people who could work to earn income for the household get sick.

Influence of Livelihood Resources on Coping Strategies

The main livelihoods resource helping households to adapt to the effects of Climate change in the River Offin basin is the financial resources. Traditionally, the main source of financial resources is from farming and exploitation of forest products which has decreased considerably over the years, with decreasing rainfall, deforestation, high temperatures accompanied by bush fires. Households with good financial resources are better adapted to cope with the impacts of climate change. Households with strong financial resources are able to replant their failed farms, buy big containers to store water for rationing, and also seek medical attention.

Over the years the people have coped quite well with water shortage, droughts, and crop damage/losses, with the help of their indigenous knowledge in agriculture and water management, acquired over many years of practice. Recently, local governance institutions and traditional authorities have provided wells fitted with hand pumps to ease the problems of bad water quality and water shortages. By-laws and tree planting programmes have also been initiated to protect the water resources in the communities. Others includes, good road network (physical resources) to ease the transportation to Kumasi, making it possible for the people to travel to Kumasi to find casual work to cope with income loss due to climate hazards and get easy access to big market centres.

CONCLUSION

There has been a significant change in the climate pattern in the Offin river basin. Whilst mean temperatures are rising, rainfall and river discharges are on a significant decline. Rainfall patterns are also showing increasing variability and this is affecting the livelihood resources of communities in the Offin basin, who are predominantly crop farmers. Their livelihood resources are heavily affected by prolonged rainfall shortages, droughts and extreme heat, leading to crop damages and great losses.

With majority of the communities depending on the Offin River and its tributaries for their water needs, they are highly vulnerable to the effects of climate change. Water resources are very sensitive to climate change so these communities are at a great risk, more so when the expected risks are already showing signs of highly uncertainty, and even expected to get worse. The way forward is to modify and integrate some of the traditional current adaptation practices that farmers themselves have adapted to response to future trends in climate change.

Heat and water-related diseases such as malaria, cholera, diarrhea and several skin diseases are expected to rise and this will have major impact on the human and financial resources of the communities. The implication is that the already poor communities will have to spend their scarce resources on disease treatment.

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Rural sector expectations on future water projects – a case study from four villages in the Deduru Oya basin in Sri Lanka

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Key words: Sri Lanka, WTP, Poverty line, Deduru Oya, Rural water supply

ABSTRACT

Sri Lanka is blessed with an average annual rainfall of 2000mm. This rainfall is sufficient enough for yearly domestic and agricultural requirements, provided that proper storage facilities with regulated runoff practices could be implemented. However, the dry zone with an annual rainfall of less than 1900mm faces both spatial and temporal water shortages. This study aims to investigate several points such as the current domestic water needs, possible future water supply mechanisms, willing to pay (WTP) for domestic water by rural village community in the Deduru Oya basin and management options for efficiency. A structured survey was conducted for 180 families randomly selected from Hedeniya and Aladeniya in the wet zone as well as Rakogama and Weerakodiyana in the intermediate zone. The results show that the average daily usage for drinking, cooking and sanitation is 115 l/p/d (liters per person per day) out of which more than 70% is used for bathing. Currently 65% use dug wells and another 16% use Tube wells while pipe born water supply is available for only 6% of the families. Contributors believe domestic water supply programs could be organized through dug wells and tube wells; however reservoirs and streams could be added in the lowland planes too. The satisfaction over water supply and maintenance by different agencies such as government, provincial councils, private sector, NGO, foreign agencies, regional councils and other agencies were also examined. The contributors prefer water supply and maintenance responsibilities be handled by the central government. However, more than 60% of contributors from Hedeniya were extremely satisfied with NGO and Foreign Agency involvement, since a FINNIDA supported water supply and sanitation project was successfully completed in Hedeniya. Major complaints of these projects were the inadequate maintenance and inefficiency of officials. A WTP survey was conducted for future water supply projects anticipated in these villages where the monthly income varies from Rs. 5000 in Hedeniya to more than Rs.15000 in Aladeniya. This survey indicates community agreement for allocation of at least 1.5% from the average monthly income. However, contributors from severe water shortage areas such as Rakogama and Hedeniya prefer allocation of more than 3.5% from the average monthly income even though their average expenditure was below the average poverty set at Rs. 1423 /p/month (per person per month). The study concluded that strong government subsidies are needed in water supply projects. People expect strong management initiatives in order to provide efficient water supply programs in Sri Lanka

INTRODUCTION

Sri Lanka is an island located about 50 km away from the southern tip of India between latitudes 5° 55’- 9° 51’ N and longitudes 79° 41’– 81° 53’ E. The island has a central mass of highlands and mountains surrounded by rolling land with rock knobs.

The island is blessed with an appreciable quantity of water to support the 20 million people living there (www.statistics.gov.lk, 2006). The mean annual rainfall varies from less than 1900mm in the dry zone to more than 2500mm in the wet zone (Figure 1). The rainfall received is sufficient enough to meet yearly domestic and considerable agricultural requirements, provided that this rainfall is stored and resulting runoff is regulated. The annual per capita water availability estimated by Samad (2005) and Imbulana and Neupane (2003) is 2300m^3. Considering the no water shortage limit of 1700m^3 (Falkenmark et al., 1990), Sri Lanka is deemed a country with no water shortage. However, recent investigations pointed out that the water stress is high in the dry zone of Sri Lanka and communities are faced with significant water shortages (Amarasinghe et al., 1999). This study aims to investigate the current domestic water needs, possible future water supply mechanisms, willing to pay (WTP) for domestic water by rural village community in the Deduru Oya basin and management options for efficiency.

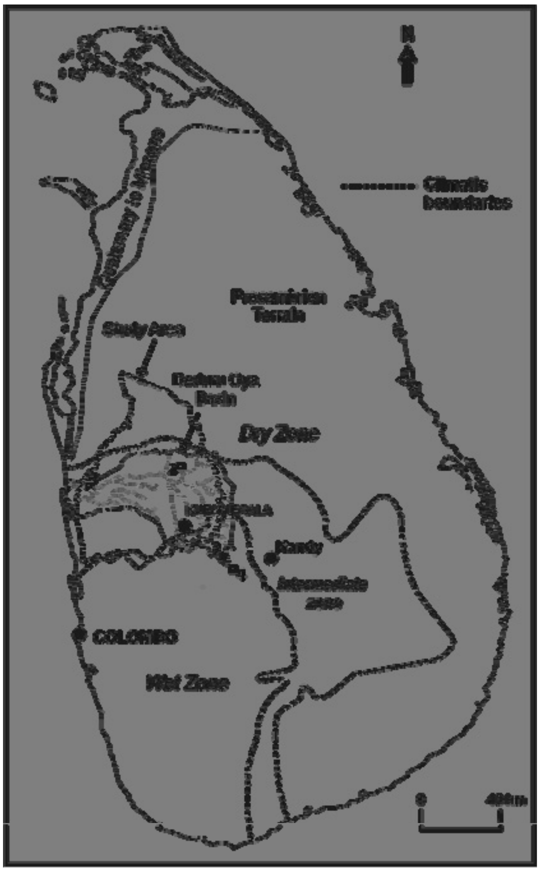

Figure 1. Sri Lanka showing major climatic zones and study locations. 1. Weerakodiyana, 2. Rakogama, 3. Hedeniya, 4. Aladeniya

METHODOLOGY

The survey was conducted over several periods from 2003 to 2005. Seven enumerators were selected and trained in the field for data collection. In the survey, 30 families from Aladeniya and 50 families each from Hedeniya, Rakogama, and Weerakodiyana were randomly selected. Per capita data on daily minimum domestic water requirements, rural area water supply, income and expenditure and monthly WTP for water supply have been collected from 180 families living in rural households.

RESULTS

Mean daily consumption of water

Mean daily consumption of water for drinking, cooking, washing, toilets and bathing were estimated by conducting the household survey (Table 1).

Table 1. Mean daily water consumption (liter per person per day).

	Drinking	Cooking	Washing	Toilets	Bathing	Total
Weerakodiyana	3.5	4.2	11.9	7.0	62.8	89.4
Rakogama	2.6	3.7	5.6	5.3	87.4	104.6
Hedeniya	3.6	5.2	11.6	9.7	126.2	156.3
Aladeniya	2.7	4.2	9.1	6.5	86.7	109.2
Average	**3.0**	**4.0**	**10.0**	**7.0**	**91.0**	**115.0**

Rural water supply

Currently 65% of families use dug wells and another 16% use tube wells while pipe born water supply is available to only 6% (Figure 2). Contributors believe domestic water supply programs could be organized through dug wells and tube wells; however reservoirs and streams could be added in the lowland planes.

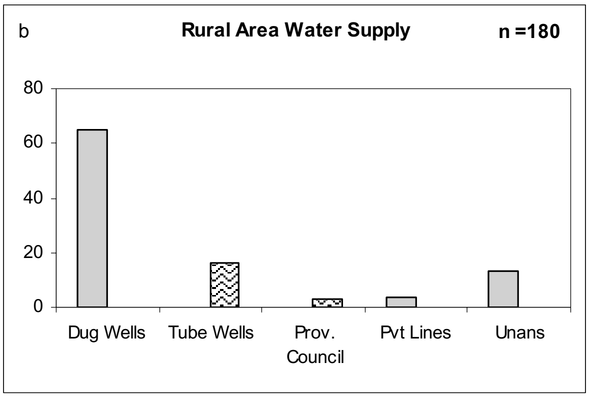

Figure 2. Domestic water supply sources in the rural areas. Shaded bars represent personal wells and hatched bars represent government initiatives.

Income and Expenditure

The monthly income and expenditure varies from Rs 5000-15000 and 4400-10300 respectively (Table 2). The most frequent monthly income and expenditure bracket ranges form Rs. 5000-10000 (Figure 3). Significant percentages (53%) of families have a higher expenditure than their income. Based on coded data analysis for the entire sample, the average income is Rs.9282 with a standard deviation of Rs.6416. The average expenditure is Rs.7771 with a standard deviation of Rs.5477. These figures are compatible with similar studies completed in the Deduru Oya basin (2002) and within Mahaweli development areas such as Kalankuttiya and Meegalewa (2003). In the Deduru Oya study the average monthly household income varies from Rs. 5143–5718 (Imbulana and Neupane, 2003). In the Mahaweli study the sample was divided in to "better off and worse off" households. The monthly average incomes vary from Rs. 6683 to Rs. 7653 while the monthly average costs vary from Rs. 4992 and Rs. 7929 respectively (www.mamasproject.org/outputs/workshops/SL soc-ec_progress_rep.pdf). The slight increase of the income and expenditure in the present study reflect the diverse income and expenditure in the urban and rural sectors. However it is worth noting that the rural sector is making progress with positive income over expenditure.

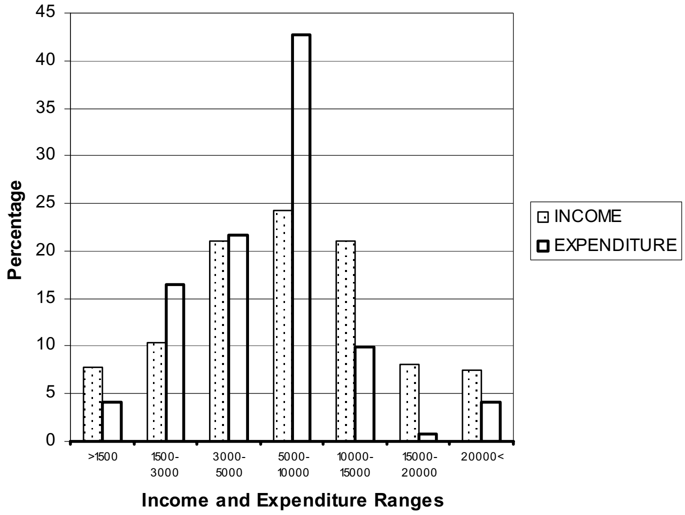

Figure 3. Percentage of monthly income and expenditure brackets in rupees for the four villages

Table 2. The averages and standard deviations of income and expenditure in rupees for the four villages

INCOME	Weerakodiyana	Rakogama	Hedeniya	Aladeniya
Mean (Rs.)	6276	7613	5000	15167
STDEV (Rs.)	4464	4719	4272	5735
EXPENDITURE	Weerakodiyana	Rakogama	Hedeniya	Aladeniya
Mean (Rs.)	5867	5760	4400	10333
STDEV (Rs.)	3409	3492	3145	6012

* The current exchange rate is Rs. 110 per US $

Monthly fee for water supply

Monthly fee structure for water supply has been examined in this section. Data on average payments as per monthly installment, maintenance as well as for 24 hour supply were collected and tabulated (Table 3). The respondents that gave a fee in the lowest category usually come from the poorest families in the villages.

However, this trend indicates the interest among the poor families for domestic water supply schemes. In the mountainous areas people are willing to pay more for the maintenance, perhaps due to recurrent maintenance needs in the rugged and difficult mountainous terrains. The complaint of inefficient officials in the water sector is also support the high maintenance payment. It is generally difficult to maintain a 24 hour supply to the community. However, if the supplier can provide a dependable 24 hour supply, people prefer to pay an additional fee (Table 3). These data results clearly explain the contributor's general understanding about the current water supply in their own region, difficulties that they have encountered and possible water management practice which could be applied in future. The figures in table 3 provide what the rural community currently pays for water. However in theory, a family spends only a meager Rs. 4800 per year for water, which would not be sufficient for implementing a good water supply project. Therefore, it needs heavy subsidies for water supply schemes, either from the government or donor agencies as similar cases have been identified in many parts of the world (Le Blanc, 2007).

Table 3. Average monthly installment, maintenance and for 24 hour supply that contributor would willing to pay (WTP) in rupees.

	Installment		Maintenance		Continuous supply	
	Mean	STDEV	Mean	STDEV	Mean	STDEV
Weerakodiyana	67	46	32	17	169	47
Rakogama	161	31	111	44		
Hedeniya	83	67	125	57		
Aladeniya	80	64	120	40	220	90
Average	98		97		195	

The monthly maintenance and installation fees with respect to contributor's percentage of income vary from 1.3 to 3.6. Families who are suffering from water shortage are willing to allocate more than 3.5% of their income while families with access to water during the dry season indicate a value below 1.6% (Table 4). However, contributors from Weerakodiyana and Aladeniya would be willing to pay an additional fee if they were assured a 24 hour continuous supply.

Table 4. The mean monthly maintenance and capital installation fees as a percentage of income.

	Income (Rs.)	Maintenance (Rs.)	Capital Installment (Rs.)	Maintenance %	Capital Installment %	Total %
Weerakodiyana	6276	32	67	0.5	1.1	1.6
Rakogama	7613	111	161	1.5	2.1	3.6
Hedeniya	5000	125	83	2.5	1.7	4.2
Aladeniya	15167	120	80	0.8	0.5	1.3

A question was posed to understand the payment difficulties associated with the contributor. Weerakodiyana is a traditional village with lower income categories and an average expenditure below the national poverty line of Rs. 1423 per person per month (Department of Census and Statistics, 2004). In Weerakodiyana, 56% of respondents reported problems with paying the monthly dues. Contributors from Weerakodiyana were not sure whether they could pay the monthly fees on time; however contributors from Aladeniya where average monthly expenditure is above the poverty line state that they could afford the payments.

DISCUSSION AND CONCLUSIONS

Our discussion will be based on the per capita and total household water usage in the Deduru Oya basin in order to determine the future direction in water management. The results show personal needs vary from 89 l/day in Weerakodiyana in the dry zone to 156 l/day in Hedeniya in the wet zone. A significant increase of water usage towards the wet zone is observed with Hedeniya consuming the greatest volume of water for bathing. More than 75% of the total domestic water requirement is used for bathing purposes. However, in the ancient periods bathing was done at common wells, irrigation tanks and diversion canals. The results indicate that to achieve a minimum acceptable quality of life, a person in the Deduru Oya basin should be provided with 115 l/day. These results could be used to regulate and control water usage in households and for future planning in domestic water supply projects.

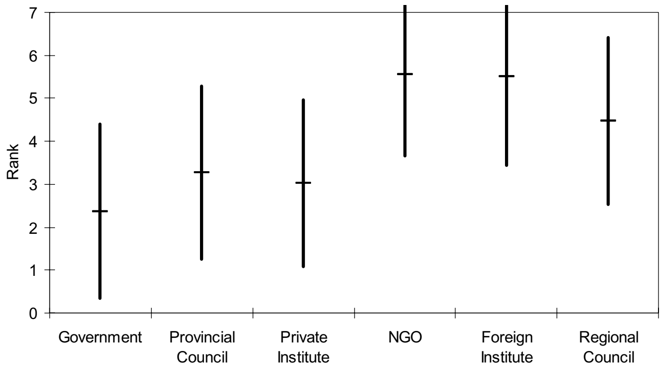

Figure 4. Peoples consent on construction, maintenance and rehabilitation of water project in Hedeniya by 1. Government, 2. Provincial Councils, 3. Private Sector, 4. NGO's, 5. Foreign Institute (FINNIDA), 6. Regional councils for the Hedeniya (n = 50).

Currently 65% of families use dug wells and another 16% use tube wells while pipe born water supply is available for only 6%. Contributors believe domestic water supply programs could be organized through dug wells and tube wells; however reservoirs and streams could be added in the lowland planes. The satisfaction over water supply and maintenance by different agencies such as government, provincial councils, private sector, NGO, foreign agencies, regional councils and other agencies were also examined. The contributors prefer water supply and maintenance responsibilities be handled by the central government. However, more than 60% of contributors from Hedeniya were extremely satisfied with NGO and foreign agency involvement, since a FINNIDA supported water supply and sanitation project was successfully completed in Hedeniya (Figure 4). Major complaints of these projects were focused on the inadequate maintenance and inefficiency of officials. A WTP survey was conducted for future water supply projects in these villages where the monthly income varies from Rs. 5000 in Hedeniya to more than Rs. 15000 in Aladeniya. This survey indicates community agreement for allocation of at least 1.5% from the average monthly income. However, contributors from severe water shortage areas such as Rakogama and Hedeniya prefer to allocate more than 3.5% from the average monthly income even though their average expenditure was below the average poverty line of Rs. 1423 /p/month (per person per month). The study concluded that strong government subsidies are needed in water supply projects. People expect strong management initiatives in order to provide efficient water supply programs in Sri Lanka. A basin wide sociotechnically driven efficient water management plan is therefore necessary in order to cope with the rural sector expectations in future water supply.

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Overview of the impacts of climate variability and climate change on runoff in Iceland

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Keywords: Iceland, discharge, variability, trend, climate change

ABSTRACT

Hydropower is the main source of electricity production in Iceland. In 2005, 80.8% of all electricity was generated by hydropower (7015 GWh). Hydropower production is affected both by variations and changes in discharge. This work focuses on studies of trends and variability found in records of discharge and climate variables, watershed modelling and analysis of a future runoff scenario for Iceland.

The variability of the atmospheric circulation strongly affects precipitation and runoff in Iceland. A study of the relationship between sea level pressure (SLP), sea surface temperature (SST), precipitation, temperature and discharge showed that the Iceland climate cannot be directly related to one or two clear patterns of SLP and SST, despite, or perhaps because of, its proximity to the northern center of action in the North Atlantic Oscillation - the Icelandic Low. There is a high geographic variability of which patterns in the general circulation affect the regional Icelandic climate and, therefore, the hydrology.

The strong decadal variability present in climate and runoff times series from Iceland obscures the detection of a climate change signal in past record. A trend analysis during the period 1961–2000 did not detected any significant increase in non-glacial discharge, despite an increase in measured precipitation. On the other hand, a significant trend was detected on spring temperatures and therefore spring floods increase and tend to occur later in the year. These detected trends in past temperature and runoff are not fully consistent with future climate scenarios and runoff changes where temperature in Iceland should increase in all seasons.

A runoff map was calculated using the WASIM watershed model for all Iceland for the period 1961–1990. This map was compared to a runoff projection for 2071–2100 according to a HIRHAM climate projection with boundary conditions from the HadAM3H model under A2 and B2 emission scenarios. The evaluation of future runoff shows that runoff may become substantially higher in 2071–2100 than 1961–1990, predominantly due to increased glacial melt caused by increased temperature. Additionally, seasonality changes in runoff are significant since higher temperatures result in less snow accumulation during winter. This projection of future runoff, therefore, implies great changes in the hydropower production potential in Iceland associated with climate change.

INTRODUCTION

The future climate might unfold in a number of plausible ways. Human emissions of greenhouse gases are known to affect the global climate system but the extent of the changes is not known and can not be evaluated with certainty yet. This is both due to the uncertainty of climate sensitivity and to the fact that it is not certain how the man-made climate forcing evolves during the 21st Century. Still, studies focusing on the effects of climate change are necessary to evaluate possibilities of adaptation and counterbalancing actions. In each of the Nordic countries, there are active and ongoing national projects in the field of climate research and climate impact assessment. The Nordic Climate and Energy (CE) research project extended from 2003–2006 and focused on the four renewable energy sources: hydropower, wind power, bio-fuels and solar energy. The CE project benefited from the national projects, and extended and integrated their work on regional scale and for cross-cutting subjects. The work presented in this paper was carried out as a part of the CE project and the Icelandic national project Climate and Energy (VO).

The water resources in Iceland are abundant due to frequent precipitation but seasonal, annual and decadal variations are strong both in precipitation and discharge. There are vast areas of post glacial lava where the permeability of the ground is high and the groundwater aquifers filter out the effects on river runoff of short term precipitation variations. Approximately 50% of the country is above 500 m a.s.l. and glaciers cover 11% of the country. Therefore, precipitation is stored as snow or ice between seasons and, in some areas, between water years, depending on temperature. Climate change is likely to have a substantial effect on seasonal snow storage, glaciers and runoff in the Nordic countries in the future. Many glaciers and ice caps are projected to essentially disappear over the next 100–200 years (Aðalgeirsdóttir et al., 2006, Jóhannesson et al., 2006).

The general objective of this study is to add to the knowledge of variability in runoff in Iceland; to evaluate whether runoff has already changed in Iceland due to man forced climate change and what changes may be expected in future runoff. To fulfil these objectives, the following research questions were set forth:

- What key modes of large scale climate variability during the past 40 years have controlled the variability in regional climate and discharge in Iceland?
- What trends are found in precipitation, temperature and discharge in Iceland during the years 1961–2000?
- According to a certain projection of changes in climate, what will be the effects on seasonal and annual runoff in Iceland?

DATA AND METHODS

For addressing the first question an empirical orthogonal function (EOF) analysis was performed on annual (hydrological years from September to August) and seasonal time series of precipitation, temperature and discharge to identify their key modes of variability during the period 1966–2004. The correlation of these EOF modes time series with individual time series of sea level pressure (SLP) and sea surface temperature (SST) was then evaluated.

Trends in annual and seasonal precipitation, temperature and discharge were evaluated both by a non-parametric Mann-Kendall test (Salas, 1993) as well as a parametric trend test described in (Jónsdóttir et al., 2007). The period considered was 1961–2000. Temperature, precipitation and discharge time series were tested on annual and seasonal basis, using four three-month seasons. Timing and magnitude of seasonal flood occurrences were tested in two periods: spring (1 March to 16 July), and autumn (17 July to 30 November). The four three-month seasons are: September–November (SON), December–February (DJF), March–May (MAM) and June–August (JJA). Additionally, trends were explored in spring and autumn mean temperature and maximum precipitation, as an attempt to relate them to trends in timing and magnitude of spring and autumn floods.

The watershed model WASIM (Jasper et al., 2002, Jasper and Kaufmann, 2003) was set up for all Iceland and produced runoff maps for the periods 1961–1990 and 2071–2100 using modelled meteorological data as input. Changes in runoff from the former period to the later were evaluated according to a future projection of climate change. The projection of climate change used was from the HIRHAM regional climate model with boundary conditions from the HadAM3H global climate model using A2 and B2 emissions scenarios.

RESULTS

Variability in regional climate and discharge

The analysis of EOF modes makes clear that the regional climate in Iceland cannot be directly related to one or two clear patterns of atmospheric variability, despite, or perhaps because of, the proximity to the northern center of action in the North Atlantic Oscillation (NAO), i.e., the Icelandic Low (IL). Correlation of the climate indices, North Atlantic Oscillation index (NAOI) and Arctic Oscillation index (AOI), with individual series of precipitation and temperature, as well as the ones from the main EOF modes, showed a seasonal and geographic variability to which extent climate indices are connected to the regional climate in Iceland (Jónsdóttir and Uvo, 2007). In several cases the AOI seems to have a higher correlation to precipitation and, therefore, discharge in Iceland than the NAOI, showing that the strength of the polar vortex may be at least as important for the regional climate in some areas of Iceland as the strength of the IL. Still, the location of the semi-permanent IL close to the country is important and often defines the predominant wind direction over the country.

The high correlation between the precipitation EOF time series and the individual series of SLP implies that if reliable seasonal forecast of SLP are available, skilful seasonal forecast of precipitation could be developed, from forecasted SLP, at least for selected areas and seasons (Jónsdóttir and Uvo, 2007). The EOF analysis made clear that the temperature in Iceland is primarily affected by the strength of meridional winds and the SST north of the country. However, a weak northeast–southwest seesaw, that accounts for 5% of the temperature variance, is associated with an NAO like pattern of the SLP. During a positive NAO, northerly winds cool western Iceland but westerly winds warm eastern Iceland to some extent.

Since watersheds act as large precipitation gauges with response depending on the geology and glaciers, the variability of the annual discharge in Iceland closely resembles the variability of precipitation except for the glacial rivers (Jónsdóttir and Uvo, 2007). In the glacierized watersheds, temporal evolution of the temperature and precipitation throughout the water year affects the annual discharge. Maps of correlation between EOF time series and SLP and SST ones suggest that the annual discharge (water year) may be estimated using autumn and winter SLP and/or measured precipitation. Additionally, the annual glacial discharge appears to have a significant correlation to the autumn SST. The spring (AMJ) discharge is affected by winter and spring temperature so that if temperature in the winter and spring is below normal, snow accumulation increases and melting season is delayed, both because of the low temperature and the thicker snow pack. These results point to the viability of forecasting spring discharge based on the general circulation patterns, temperature and precipitation of the preceding seasons.

Trends in discharge series

The analysis of annual and seasonal discharge in Icelandic rivers shows no significant trends (Jónsdóttir et al., 2006, Jónsdóttir et al., 2007). Even if not statistically significant, some trends series show slightly positive trends, corresponding to positive ones found in precipitation. Regarding trends in spring and autumn flood and mean discharges, the slight trends, some positive, other negative, over the period 1961–2000, are generally not statistically significant. The trends found, in temperature and precipitation, do not relate directly to trends in discharge, but the observed patterns of slight trends suggest hypotheses for further study.

Spring floods appear to occur later and tend to be larger; these are generally snowmelt floods. Low spring temperatures can delay snowmelt floods, and the maintenance of lower than normal temperature into the spring increases the chance of rapid warming and large snowmelt flood may result. Trends in autumn maximum discharge show a decrease at most stations which may be associated with increasing temperatures and, therefore, less snow accumulation and less frequent autumn snowmelt floods caused by warm spells. These trends can also be associated to the decreasing trend in maximum precipitation in central Iceland during autumn. The slight increase of autumn floods at some stations may be explained by the negative trend in spring temperatures; the floods caused by snow melt in the spring are generally higher than the autumn floods and if the "spring" snow melt is delayed into the autumn season, these may become higher than the traditional autumn maximum discharge.

A runoff map and a projection of future runoff

The runoff of Iceland has been evaluated for the time period 1961–1990 with the hydrological model WASIM using meteorological data from the PSU/NCAR MM5 numerical weather model (Jónsdóttir, 2007). According to the runoff map, the average surface runoff during 1961–1990 was 1460 mm/year, evaporation was 280 mm/year, subsurface runoff to the ocean was 40 mm/year, and the advance of glacier during the period accounts for an increased storage of 20 mm/year if distributed over the whole country.

The climate projection used in this study shows a mean increase of 2.8°C in temperature and 6% in precipitation by 2071–2100. According to the runoff projection, the average runoff will increase to 1800 mm/year during the years 2071–2100, i.e. almost 25% higher than during the years 1961–1990. Glacial covered areas are reduced by 20%. Runoff from non-glaciated areas increases by 8%, partially because non-glaciated areas have increased, while glacier runoff increases by 90%. The change in seasonality of runoff is shown in Fig. 1 which is divided in three parts: a) runoff change for the whole country, b) runoff from non-glaciated areas, where runoff increases in all months except May–August because of higher temperature during winter and, therefore, less snow accumulation, and c) runoff from glaciers. Even though glacier covered areas are reduced by 2400 km^2, the runoff from glaciers is substantially higher during the years 2071–2100 than during the years 1961–1990. The melting of glaciers, and consequent temporarily increased melt water, is clearly the most pronounced change in this projection of future runoff.

According to the projection, average evapotranspiration will be 340 mm/year for the years 2071–2100. Calculated gravitational potential power of runoff is 220 TWh/year for the whole country for the years 1961–1990 and 320 TWh/year for the years 2071–2100.

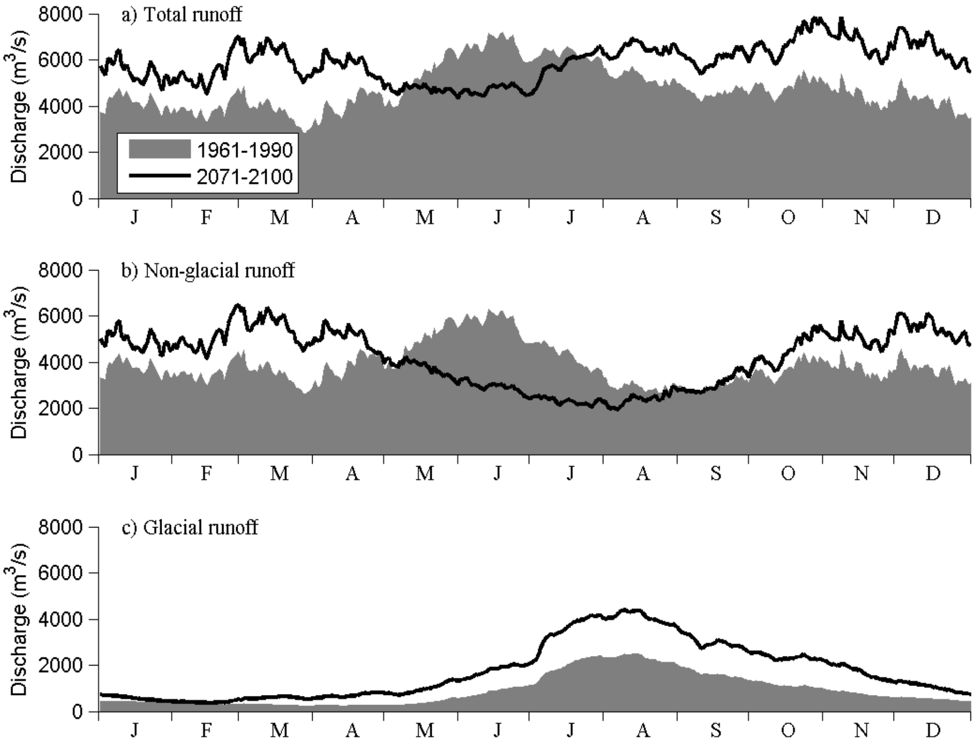

Figure 1. Change in the seasonality of mean runoff between the periods 1961–1990 and 2071–2100. a) Runoff from all of Iceland. b) Runoff from non-glaciated areas (3% larger area in the future scenario). c) Runoff from glaciated areas (20% smaller area in future scenario).

CONCLUSIONS

The EOF analysis of SLP, SST, precipitation, temperature and runoff over Iceland evidenced some patterns of SLP and SST that correlate with regional precipitation and runoff in Iceland and in some seasons a causal relationship could be established. Additionally, the results of the analyses reveal that seasonal hydrological conditions in Iceland could be forecasted based on precipitation, temperature and general prevalent circulation patterns of preceding seasons.

Trends appear in precipitation and temperature in Iceland but no clear trends appear in annual discharge for the time period 1961–2000. Still, there is a tendency for spring floods to occur later and to be larger; these are generally snowmelt floods and the delay may be connected to a negative trend in spring temperature. Due to large decadal variability, one can not determine whether the trends found are due to natural variability or due to climate change. The trends found in precipitation agree with projections of some precipitation increase in Iceland due to anthropogenic climate change forcing, but the decrease in spring temperature and the corresponding delay of spring floods is not indicated by the projection of regional climate and runoff evaluated.

The evaluation of the effects of climate change on water resources is based on a future climate simulation from the HIRHAM regional climate model with boundary conditions from the HadAM3H global climate model using A2 and B2 emissions scenarios. Future runoff is shown to become substantially higher in 2071–2100 compared to 1961–1990, predominantly due to increased glacial melt caused by increased temperature. Furthermore, seasonal changes in runoff will be substantial. Thus, according to this projection there may be great increase in hydropower production potential associated with climate change in Iceland.

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Projected changes in heavy precipitation and snow cover in Finland

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Keywords: Climate change projections, maximum one-day precipitation totals, snow water equivalent, snow cover days.

ABSTRACT

Changes in heavy precipitation and snow cover in Finland by the end of the 21st century were analyzed based on experiments performed with a set of regional climate models (RCMs). Increases in the maximum one-day precipitation totals were projected in all seasons. *The largest percentage reductions in the number of* days with snow cover and in the average liquid water-equivalent content of snow *were found* in autumn and spring, rather than in winter. The two general circulation models (GCMs) providing lateral boundary conditions for the RCMs were responsible for a considerable part of the differences among the various RCM simulations, particularly so in winter.

INTRODUCTION

Extreme events characterized by scanty or excessive precipitation or snow cover may have considerable environmental and socio-economic consequences. Torrential rainfall increases soil erosion and chemical leaching, and may result in flooding. Opposing events, i.e. prolonged periods with little rain, cause drought, decrease surface- and groundwater levels and can bring on severe problems with water availability. Abundant snow raises the costs of road clearance and imposes loads on the roofs of buildings and crowns of trees, while lack of snow is harmful for ski resorts and for hibernating plants and animals.

The current paper provides projections of heavy precipitation and snow cover on the basis of daily output data from experiments performed with a suite of regional climate models (RCMs). We consider here the maximum 1-day precipitation total (R1d) and *the number of* days with snow cover (SCD), as well as mean precipitation (P) and the average liquid water equivalent of snow (SWE). Future changes in these variables have implications for flood management and hydropower resources, among others. As regards R1d, the paper is linked with a study of heavy precipitation and urban floods, described by Silander et al. (2007). The main focus lies on changes in Finland; for a wider spatial scale of some aspects, see e.g., Ruosteenoja et al. (2006), Beniston et al. (2007) and Jylhä et al. (2007).

METHODS

The regional climate model experiments employed here to provide dynamically downscaled high-resolution climate change scenarios are listed in Table 1. Most RCMs contained an atmospheric component only, although in two of them a submodel for the Baltic Sea was utilized. The sea surface data and atmospheric lateral boundary values were mainly derived from the global HadAM3H climate model, applying the IPCC-SRES A2 scenario. Some simulations were also conducted for the B2 scenario, and a few RCMs additionally regionalized information from an alternative general circulation model, ECHAM4/OPYC. All the RCMs contributed to the EU project PRUDENCE (Christensen et al., 2007) and/or to the Nordic project Climate and Energy (CE).

Simulated 30-year mean indices of heavy precipitation and snow during the baseline period 1961-1990 and the future period 2071-2100, were first calculated in the original model grids and then interpolated onto a common latitude-longitude grid. Changes in the 30-year seasonal mean values are given here as maps or as domain averages. Winter refers to December-February (DJF), spring to March-May (MAM), summer to June-August (JJA), and autumn to September-November (SON).

Climate scenarios inferred from downscaling of solely two GCMs may comprise only a small subset of possible future evolutions. It is therefore essential to put the projections into the perspective of a wider range of plausible scenarios. For that purpose, we apply the multi-GCM data set generated for the IPCC 4th Assessment Report, i.e. the CMIP3 archive, and also refer to projections based on the previous generation of GCMs.

Table 1. The regional climate model experiments considered here, with the following characteristics defined: the model acronym; country of origin; acronym of the driving GCM (see the footnotes) and the SRES scenarios employed, together with the number of ensemble simulations (in parentheses). The final column indicates which of the following variables or indices are considered: mean precipitation (*P*), the maximum one-day precipitation total (R1d), *the number of* snow cover days (SCD), snow water equivalent (SWE).

Model	Country	Driving GCM – SRES scenario (# of runs)	Variables/indices
CHRM	Switzerland	H-A2	*P*, R1d, SCD, SWE
CLM	Germany	H-A2	*P*, R1d, SCD, SWE
HadRM3H	UK	H-A2	*P*, R1d
HadRM3P	UK	HP-A2(3), HP-B2	*P*, R1d
HIRHAM (dk)	Denmark	H-A2(3), E'-A2(3), E'-B2	*P*, R1d, SCD, SWE
HIRHAM (no)	Norway	H-A2, H-B2	*P*, R1d
RACMO2[1]	Netherlands	H-A2	*P*, R1d, SCD, SWE
RCA3	Sweden	E-A2, E-B2	*P*, R1d
RCAO	Sweden	H-A2, H-B2, E-A2, E-B2	*P*, R1d, SCD, SWE
REMO	Germany	H-A2	*P*[2], R1d[2], SCD, SWE

[1] indicates not available for the entire domain; [2] denotes not used for summer and autumn. Acronyms in col. 2: H stands for the HadAM3H AGCM, HP for the HadAM3P AGCM, and E and E' for two parallel runs by the ECHAM4/OPYC3 AOGCM.

RESULTS

Heavy precipitation

A trend towards heavier one-day precipitation amounts was consistent across all model simulations considered, irrespective of the SRES scenario and the driving GCM (Fig. 1). In winter the mean precipitation tended to increase more (in %) than the one-day extremes. The situation was vice versa in summer and, according to most model experiments, also in spring and autumn: several experiments with negligible changes or even decreases in *P* nonetheless yielded increases in R1d. There was a close correlation between the projected changes in R1d and *P* in winter and summer but less so in the remaining seasons.

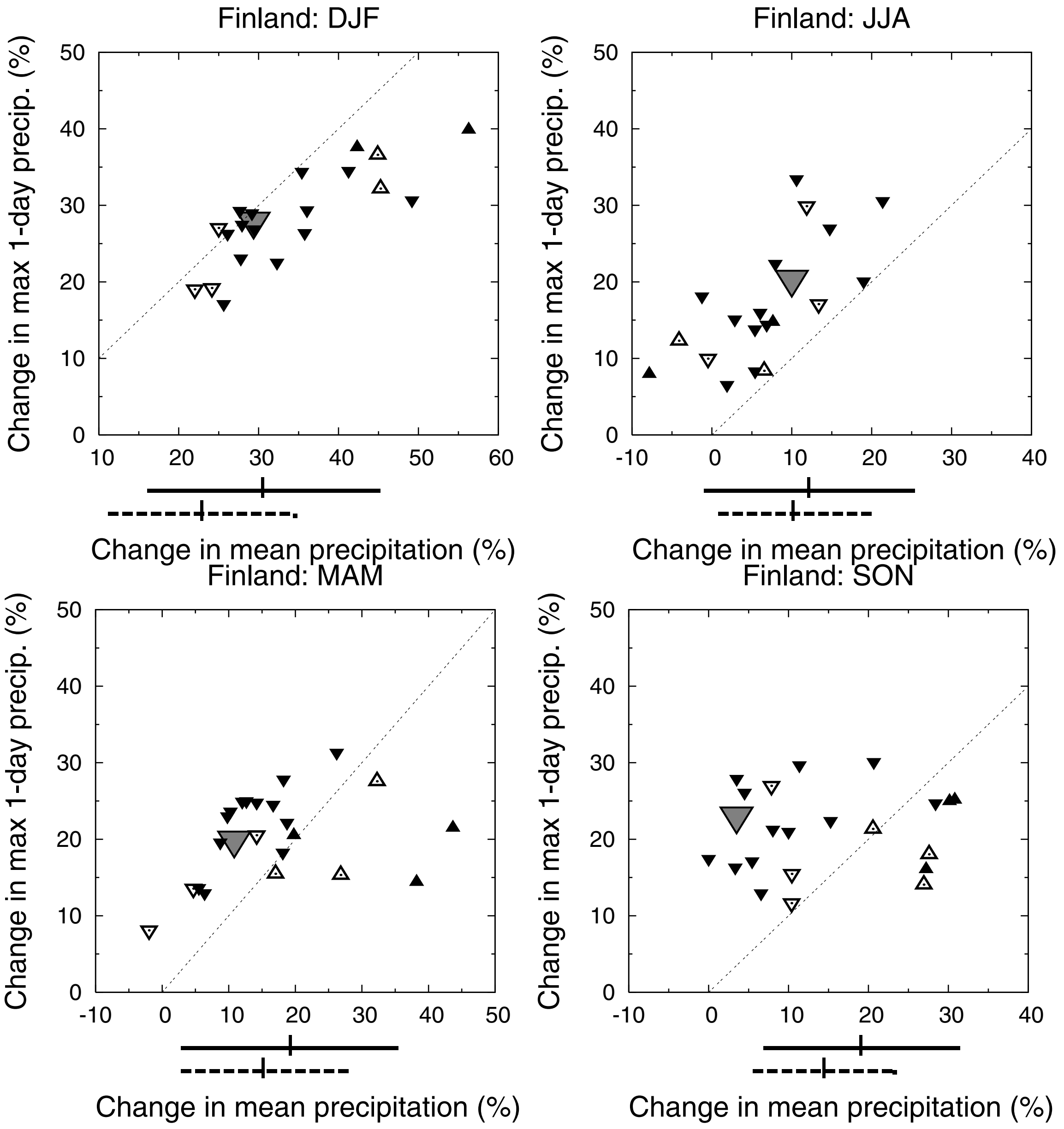

Figure 1. Projected area-averaged changes (%) in the 30-year means of the greatest 1-day precipitation total (R1d) in winter (DJF), spring (MAM), summer (JJA) and autumn (SON) by 2071-2100, relative to the baseline period 1961-1990, as a function of the seasonal mean precipitation changes in Finland. The small solid (open) triangles pointing downward refer to the H/HP-A2 (H/HP-B2) runs, the larger one denoting to the A2 experiments by the driven HadAM3H. The solid (open) triangles pointing upward refer to the E-A2 (E-B2) runs. The horizontal solid (dashed) bars below each scatter diagram indicate the best estimate and the 90% interval of the precipitation change for the A2 (B2) scenario based on 19 GCMs (see text for details).

The differences between the A2 and B2 scenarios were rather small compared to the spread among the model results. In general, the RCM-based projections were mainly scattered around the projections given by the driving GCMs. The ECHAM4/OPYC-driven RCM simulations projected larger changes in winter R1d and *P* than the HadAM3H-driven ones. This appears to be related to different responses in the wintertime atmospheric circulation in the two GCMs (Räisänen et al., 2004; Christensen and Christensen, 2006; Déqué et al., 2007).

In order to place the projections based on the dynamical downscaling of a few global climate simulations into a wider perspective, area-averaged seasonal mean precipitation changes inferred from A2 and B2 experiments with 19 GCMs are shown in Fig. 1. In addition to the best estimates (i.e., multi-GCM means), the 90% intervals (i.e., mean±1.645×standard deviation of the GCM simulations) are presented (for details, see Ruosteenoja and Jylhä, 2007). It appears that the set of the RCM experiments employed here actually produced a rather wide range. Although most of the RCM-based projections of *P* fell inside the GCM-based intervals, there was a tendency towards larger increases in winter and spring, and smaller increases (or even decreases) in summer and autumn, compared to the GCM-derived ranges. As far as the GCM-based best estimates for changes in *P* under the A2 scenario are considered, Fig. 1 suggests that they are roughly accompanied with the following changes in R1d: 20-30% in winter, 15-30% in spring, 10-35% in summer and 10-30% in autumn.

Snow cover

Averaged over the whole country, the mean annual number of snow cover days for the A2 scenario was projected to decrease by about 25-40%, the range resulting from the scatter among the RCM simulations. The corresponding area-averaged reductions across the various A2 experiments were about 50-75% in autumn, 5-20% in winter and 35-50% in autumn. The multi-RCM mean declines in annual SCD varied from less than 30% in northern and eastern Finland to about 50% in the most south-western part of the country. The percentage reduction was everywhere weaker in winter than in the transition seasons (Fig. 2). In northern Finland during December-February, SCD was projected to remain nearly unchanged. The ECHAM4/OPYC-driven RCM simulations produced larger changes in SCD than the HadAM3H-driven ones. Under the B2 scenario SCD likewise reduces, albeit not as much as under the A2 scenario.

Changes in SCD were closely related with decreases in the mean snow water equivalent, percentage reductions in the former remaining smaller than in the latter. The RCM-simulated responses of the nationally-averaged mean SWE to the A2 scenario approximately varied from -70% to -90% in autumn, from -50% to -70% in winter and from -60 to -80% in spring. Comparable results were obtained by Ruosteenoja et al. (2005) on the basis of four global models belonging to the previous generation of GCMs. According to them, during midwinter about 60% of snow is lost in the south and 40% in the north. In the last spring month with snow, the GCM-simulated reduction was more than 90%.

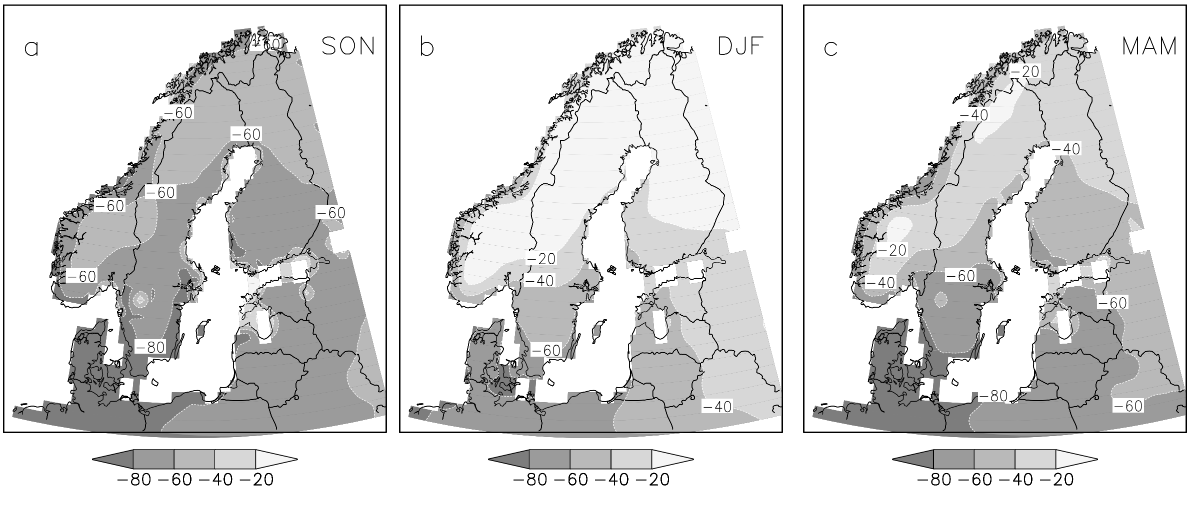

Figure 2. Projected multi-model mean change (%) in the 30-year mean number of snow cover days (SCD) over land areas in (a) autumn, (b) winter and (c) spring by 2071-2100, compared to 1961-1990, based on six RCM simulations for the SRES A2 scenario. The contour interval is 20%.

DISCUSSION AND CONCLUSIONS

Increases in the maximum one-day precipitation totals were projected in all seasons, particularly so in winter. *The largest percentage reductions in the number of* days with snow cover and in the average liquid water-equivalent content of snow *were found* in autumn and spring, rather than in winter. In general, the ECHAM4/OPYC-driven RCM simulations projected larger changes in snow cover and extreme precipitation than the HadAM3H-driven ones, which was also true for mean air temperature and precipitation.

Changes in several climate variables, with accompanying changes in hydrology, appear inevitable, regardless of any foreseeable reductions in emissions. Consequently, it is essential for the sectors influenced by precipitation and snow to be prepared for the changes. Adaptation measures can be used to counter the adverse effects or exploit the benefits of the anticipated changes. The economic impact of climate change on outdoor recreation and winter tourism, for example, depends not only on local changes in temperature, rain and snow, but also on regional- to continental-scale changes in climate, which will affect national and international competition among tourism enterprises.

Proper and timely adaptation to climate change and its impacts should be based on the best available knowledge of the current and future climate. The Finnish research programme on adaptation to climate change (ISTO), aiming to ensure science-policy interaction, produces and disseminates information needed for planning practical adaptation measures. Within the programme, researchers on various fields (agriculture and forestry, water resources, biodiversity, urban planning, built environment) were inquired about their specific needs for climatic knowledge. Based on the questionnaire, the procedure for analysing climate observations and constructing climate scenarios was adjusted. The process comprises several parallel activities, a part of them described by Venäläinen et al. (2007), Ruosteenoja and Jylhä (2007), and Ruokolainen and Räisänen (2007), as well as in this paper.

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Hydrological regime stability and water resources systems under the climate change conditions

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Keywords: climate change, river flow regime, water resources sensitivity indicator

ABSTRACT

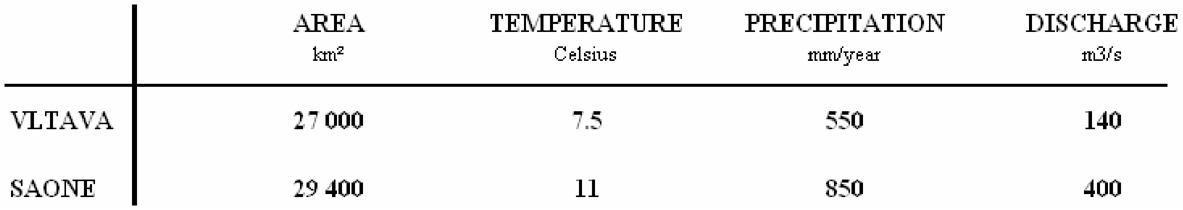
The investigation of climate change impact on water resources and hydrological regime stability is carried out in two different regions – the Saône river basin (France) and Vltava river basin (Czech Republic). With respect to existing water resource management systems, it is necessary to develop tools for assessing the water resources situation in present climate conditions as well as under the conditions of climate change. Therefore, the sensitivity indicators are build up including the effect of the basin structure on aggregation of the hydrological regime downstream. Having two model river basins in different geographic regions enables us to investigate the influence of basin spatial structure and climatic conditions on hydrological regime. The preliminary suggestions for the indicators and climate change scenarios are presented and discussed.

INTRODUCTION

As the water resources are one of the most important factors in the welfare of the society, it is necessary to assess the possible effects of the upcoming climate change. The lack of the water is often a constraint on the economic development of a country (Arnell, 2004). Position of the Czech republic on the hydrological divide predetermines the hydrological regimes to be sensitive to climate variability and fluctuations. In the last decade, Czech republic has experienced several serious hydrological extremes. Not only the floods in 1997 and 2002 with really extreme return periods, but also the 2006 snowmelt spring flood and especially the 2003 summer drought. The significant periods of drought occured in the Saone river basin in last years as well (2005 for example). As the climate change is very likely to occur in next decades, it is often claimed, that the probability of repeating this drought situations are likely to increase. The possibility of drought situation under the upcoming climate change is examined in the article.

Two river basins were used as an examples of different climatological regions and different spatial structure of the river network. Whereas Vltava serves as an example of the river driven by snowmelt, the Saone is mostly driven by the winter precipitation. However, both rivers experience the main drought period during late summer and early autumn months. Comparison of both rivers is briefly presented in table 1.

Table 1. Basic characteristics of the studied river basins



	AREA km²	TEMPERATURE Celsius	PRECIPITATION mm/year	DISCHARGE m3/s
VLTAVA	27 000	7.5	550	140
SAONE	29 400	11	850	400

METHODS

Climate change scenarios definition

For assessing the effects of climate change the results of global climate models (GCM) were used. Also the regional climate models are available in the PRUDENCE project. The analyses of climatic variables were done on the basis of both GCM experiments results and the results of the PRUDENCE project (Christensen et.al., 2007). This counts for more than 40 variants of climate change scenarios. However the results from both GCMs and RCMs are in general consistent, finally the results from RCMs were used to create a climate change scenario, especially because its better ability to express the local climatic conditions. This is possible especially because of its much finer spatial resolution (fig.1).

As the hydrological regime is mostly driven by temperature and especially precipitation, these two variables were analysed. To compare the present climatological conditions with the future, two reference periods were used – control period of 1960-1990 and scenario period of 2070-2100. Scenario desaggregation is a wild topic for research. Yet, as far as low flow is concerned, usual shifting of observed values or more sounded stochastic desaggregation techniques are equally valid.

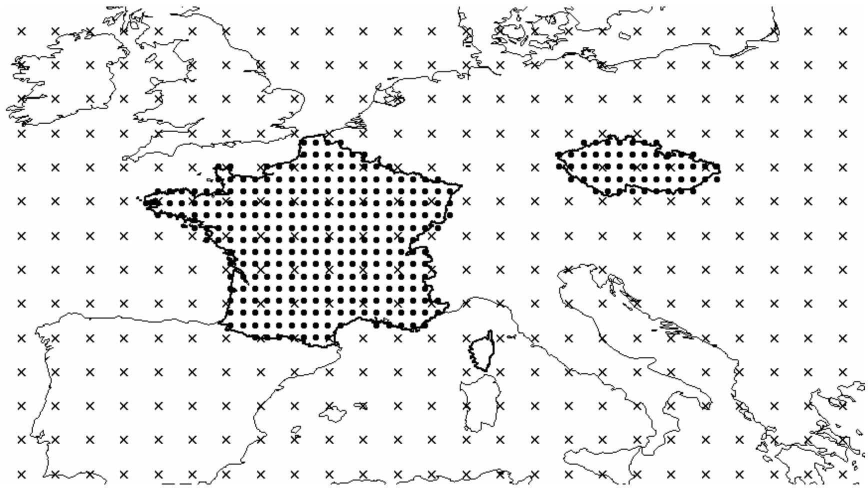


Figure 1. Comparison of the available grid cells of GCM (crosses) and PRUDENCE Regional Climate Model (dots); GCM of National Centre for Atmospheric Research was taken as an example, however it represents the finest possible spatial resolution of present GCMs

WATER RESOURCES SENSITIVITY INDICATOR

Daily discharge timeseries for Vltava and Saone river were used for estimating the sensitivity indicator. These cover the control period between 1960-1990 and will be later used to compare the effects of climate change. There are more than 30 gauging stations for both river basins, which enables us to cope with the spatial structure of the river network and later identify the sensitivite areas of the basins. Hydrological model GR4 will be applied for simulation on subbasin level.

The indicator was build up to take into account especially the variability of the flow with respect to assessing the drought events. The example is shown on figure 2, where the flow regime of one of the Vltava subbasins under the present and future climatic conditions is sketched. The assumption is, that the sensitivity of the river flow to climatic forcing could be assess by the coefficient of variability (CV) of the “available water flow” – the water, which stays in the stream after some part of the water was taken out for water use. A higher value of this available water flow CV will have much significance for areas downstream and can be a hint to potentially pre-conflicting situations. Also the hint for estimating the sensitivity indicator on the basis of the available water is outlined in figure 2.

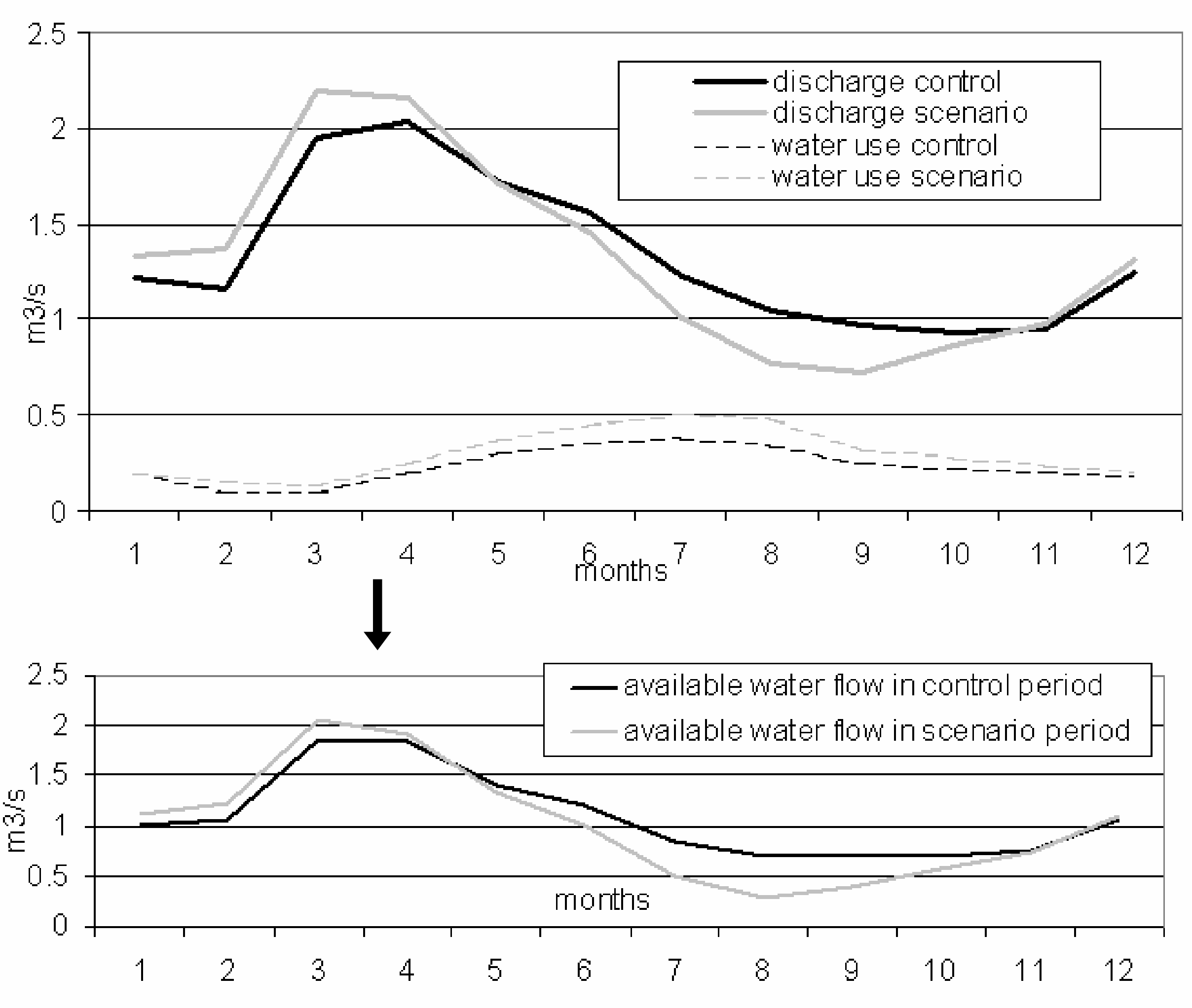


Figure 2. Hydrological regime of the Ostružná river (one of the Vltava subbasins) under present and future climatological conditions (from Kavan, 2007) with the sketch of approximate water use and "available water flow". The plot is interannual flow, but the sugested indicator will cover both shift in mean and change in CV in the low flow period.

RESULTS

Climate change scenarios

The analysis of GCM and RCM climate change projection shows the increasing trend of temperature during the century in the area of Czech republic as well as in France. Figures 3 and 4 shows the example of RCM simulation result. However the course of the temperature during the century is different for each scenario, the dominant rising trend is obvious for each of them.

According to the analyses of regional climate models for Europe, the increasing temperature trend for Czech republic is obvious with the total increase of 3.3 degrees of Celsius between the control period of 1960-1990 and future period of 2070 – 2100. The projection of the temperature annual regime doesn't indicate a big change; the higher temperatures are obvious throughout the whole year. More interesting situation can be found in case of precipitation, where the shift of the summer drought period to earlier part of the year is clear. Not only shift in the timing of drought period, but also the decrease in the amount of summer precipitation could be expected. The increase in winter precipitation is also obvious. The annual regime of precipitation and temperature is shown in figure 5.

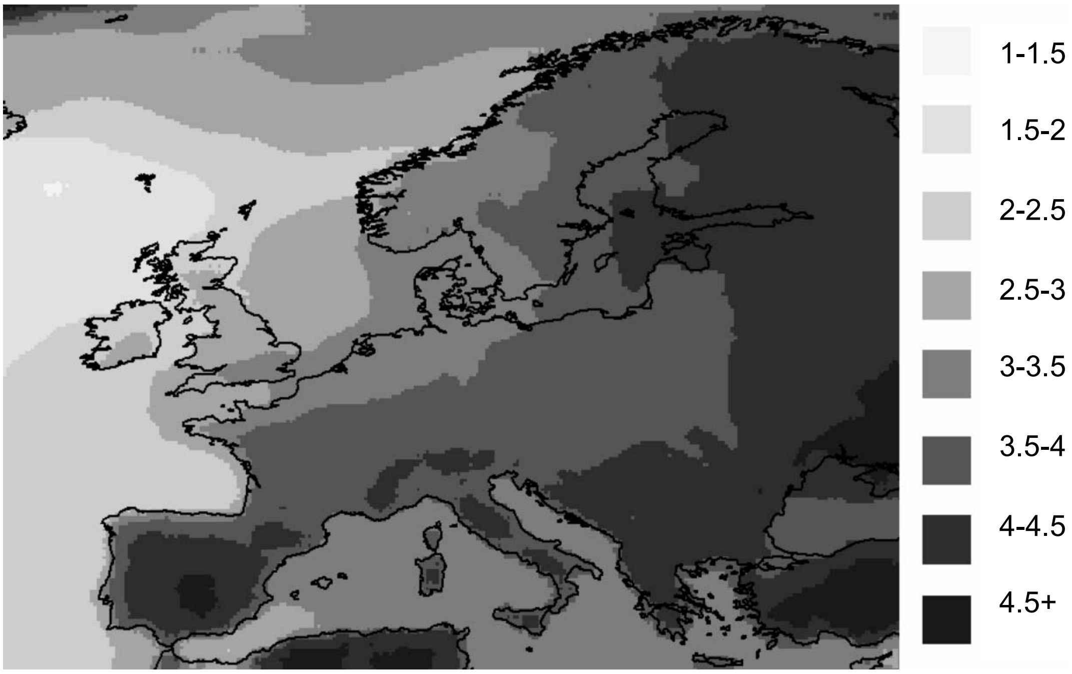


Figure 3. ***RCM temperature difference between 1960-1990 and 2070-2100 (in ^{o}C)***

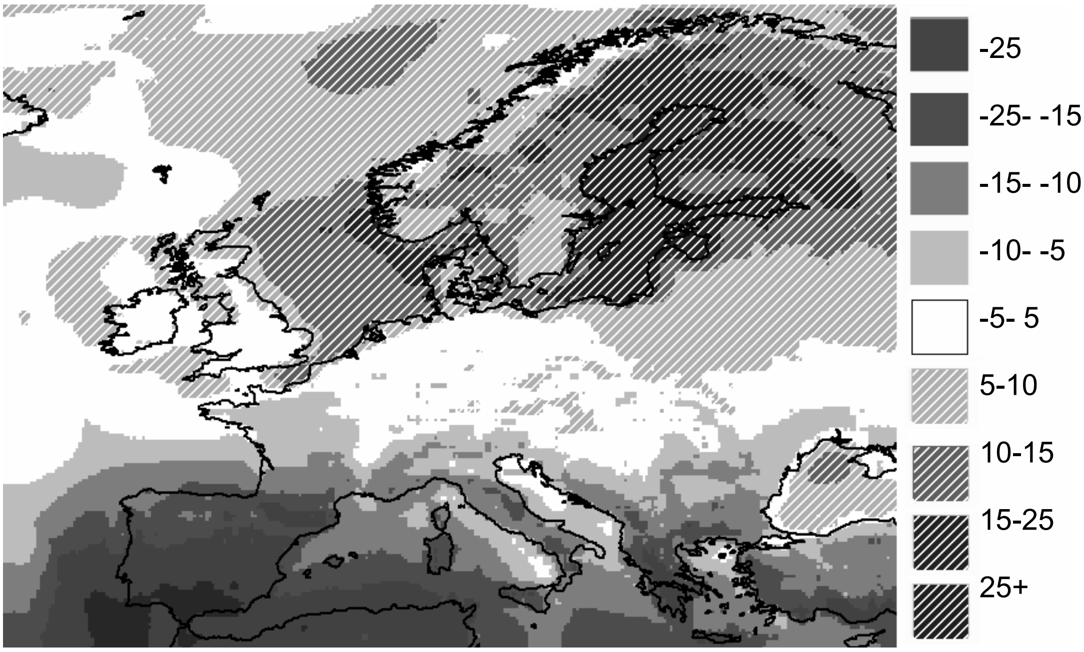


Figure 4. ***RCM precipitation difference between 1960-1990 and 2070-2100 (in %)***

The same is true for France in the case of temperature. According to the model results, the rising trend throughout the year with the total increase of 3.6 degrees of Celsius between the control and scenario period is awaited. The situation in case of precipitation is different, because the decrease of the total amount of precipitation should be expected. The decrease between control and scenario periods counts for 5-10%. On contrary to the case of Czech republic, there is no shift in the timing of the annual minimum and maximum. But the important thing is the fact, that the extremes are more pronounced; the monthly minimum in August is up to 20% lower comparing to the control period. The annual regime of temperature and precipitation for France is graphically expressed in figure 6.

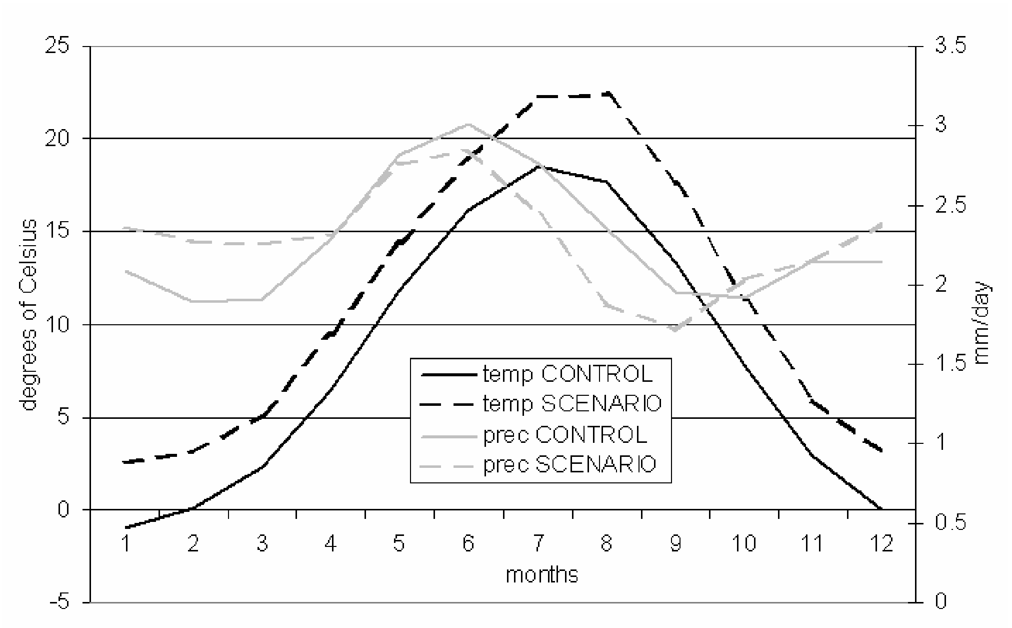


Figure 5. Comparison of precipitation and temperature in the area of Czech republic between the control period (1960-1990) and the scenario period (2070-2100)

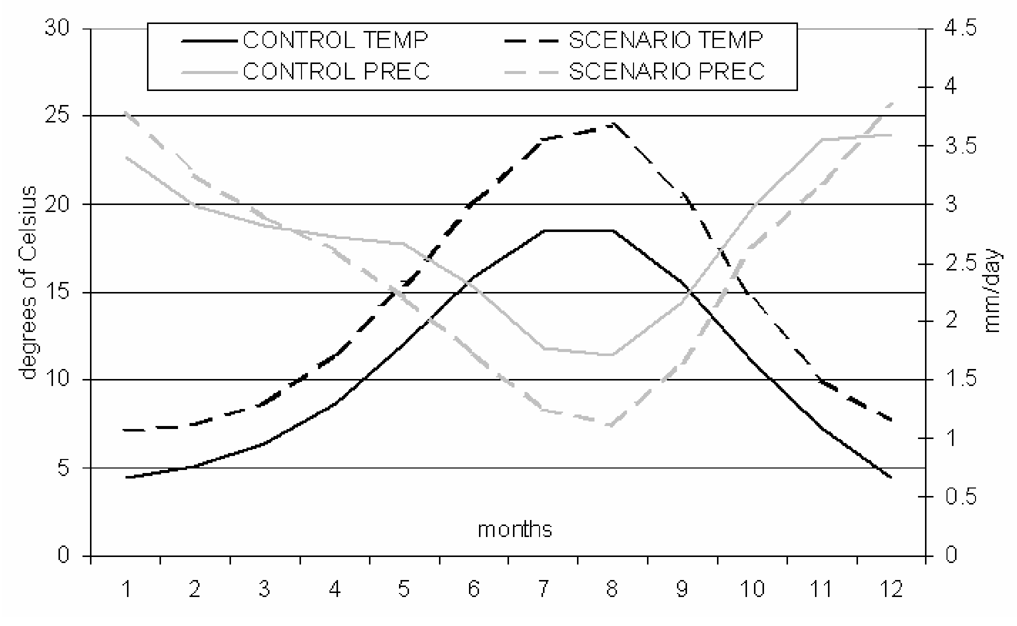


Figure 6. Comparison of precipitation and temperature in the area of France between the control period (1960-1990) and the scenario period (2070-2100)

DISCUSSION AND CONCLUSION

The phenomenon of climate change is a topic, which is necessary to take into account with respect of water management planning. Nevertheless, our knowledge in this field is still very limited and affected by a high uncertainty, starting at the level of emission scenarios through climate modelling and finally hydrological modelling. However, some general trends in both evolution of global climate and also local hydrological situation can be outlined.

At first, it is the behaviour of a global climate, which shows the increasing trend of temperature of about 3 °C and approximately 10% increase in precipitation. Even if the global trends are clear, the regional response to climate change is a bit different in all GCM experiments. In case of climate behaviour in Europe, the increase of temperature on the whole continent is obvious with larger changes in the continent interior. This should be counted to the effect of ocean temperature momentum. It is much more difficult to express the trend in precipitation. However the general trend of precipitation shows slight increase, this is not the case of the whole Europe. The southern part of Europe is supposed to suffer by decreased precipitation and on the other hand the northern part will experience the increase of precipitation. The boundary between decrease and increase of precipitation is a bit different in each model, but in general it is usually placed between 50-55N of latitude (Arnell, 1999). The decrease of precipitation can be expected for the region of France and there is almost no change in case of Czech republic. Nevertheless, the important fact, which is regarded to hydrological regime, is the shift in the precipitation regime (especially for Czech republic) and especially the prolonging of the drought period.

These two basic climate variables – temperature and precipitation – together with increase of evapotranspiration will affect the hydrological regime. The frequency and length of drought periods are very likely to increase (e.g. Huntington, 2005). However the study is not yet finished, the preliminary results of the climate change scenarios give us a hint about the future conditions. After defining the sensitivity indicator into its final shape, it is believed to help to identify the sensitive areas of both basins and also to evaluate the effect of different spatial structure of the basins.

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Long Term Changes of Hydrological processes in Inland Waters of Latvia*

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Key words: long term variability, discharge, trends, Latvia

ABSTRACT

The study of changes in river discharge is important for the development of efficient water resource management system, as well as for the development and validation of climate change impact models. The hydrological regimes of rivers and their long term changes in Latvia were investigated. Four major types of hydrological regimes of rivers, which depend on climatic and physico-geographic factors, were characterized. These factors are linked to the changes observed in river discharge. Periodic oscillations of discharge intensity and low- and high-water flow years are common to the major rivers of Latvia. A frequency of river discharge regime changes of about 20 and 13 years was estimated for the studied rivers. A significant dependence of the river discharge regime changes on the climate change has been found.

INTRODUCTION

A thorough investigation of the increasing human impact on the environment and studies of environmental change are of utmost importance. Long term observations of hydrologic systems provide time series of evapotranspiration, precipitation, and river discharge. These data series can be analysed from different points of view. Future climate changes may have substantial impacts on river discharge patterns, as well as on extreme events, their magnitude and probability of occurrence (Krasovskaia and Gottschalk 1993). River discharge data can also be used to validate hydrological cycle calculations in climate models. River discharge time series have been extensively studied worldwide. The relevant trends regarding global climate changes have been identified in Nordic countries (Rosenberg *et al.* 1999; Vehviläinen and Huttunen 1997). In Finland, climate change may result in the increase of mean discharge by 20-50 % (Vehviläinen and Lohvansuu 1991). Commonly, river discharge patterns have been studied in terms of linear trend analysis, even though they can be much more complex (Pekarova *et al.* 2003). Analysis of river discharge patterns is important for the Baltic countries, which are located in a climatic region directly influenced both by atmospheric processes in the Northern Atlantic and by continental impacts from Eurasia.

The earliest observations of river discharge in Latvia can be dated back to the 19th century for the Daugava River, and long series of data have been accumulated. Studies conducted on river discharge trends in Estonia confirm the importance of such analysis (Jaagus *et al.* 1998). Discharge analysis in respect to global climatic changes is also very important at present, considering the predicted changes in this region.

The aim of this study is to analyse the hydrological regime and long term changes of river discharge in Latvia.

METHODS

The study area covered the whole territory of Latvia, but also reference sites of rivers in neighbouring areas were used. In Latvia, there is a dense net of rivers flowing through quaternary sediments. The total number of rivers is 12 500, of which only 17 are longer than 100 km. The total length of rivers is ~ 37950 km and the mean density of the river network is 588 m per 1 km^2. The average annual runoff of rivers is about 35 km^3, of which more than 50 % forms in neighbouring countries. The

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hydrological regime in rivers is influenced not only by the climate (precipitation and air temperature), but also by factors such as geomorphology, geological structure, soil composition, and land-use patterns (Table 1). The coverage of lakes and wetlands in river basins also affects the river stream flow. More than 90 % of the total runoff in Latvia is comprised by the five largest rivers.

Table 1. Characteristics of the studied rivers

River	Basin size, km^2	Length, km	Water runoff, km^3/year	Forest area, %	Bog area, %	Agricultural area, %
Daugava	87900	1005	20.4	43	5	50
Lielupe	17600	119	3.6	22	3	71
Venta	11800	346	2.9	32	5	62
Gauja	8900	452	2.2	47	5	48
Salaca	3420	95	0.95	34	15	45
Bārta	2020	98	0.63	-	-	-
Irbe	2000	32	0.44	-	-	-
Tulija	57	15	0.018	-	-	-

The climatic conditions of Latvia are dominated by the transport of cyclonic air masses from the Atlantic Ocean, leading to a comparatively high humidity, uneven distribution of atmospheric precipitation through the year, mild winters and moist summers. In general, the spatial heterogeneity of the climate of Latvia is determined by physiogeographical features, such as upland relief, distance to the Baltic Sea, and the cover of forests and mires. Data used in this study were obtained from the Latvian Environment, Geology and Meteorology Agency.

Discharge measurements covered the last 65 years for the Gauja River and 125 years for the Daugava River. For trend analysis, mean annual discharge values calculated as arithmetic means from monthly records were used. The stream flow data have been tested by Fisher test for data homogeneity before the analyses of variability. Obtained results indicated that time series of river flow are homogenous ($F_{emp}<F_{theoretical}$, p=0.05) for all selected rivers.
For the calculation of the periodic changes (oscillation) of discharge, moving average (a step of 6 and 10 years) values of discharge data as well as integral curves were used. The use of integral curves, which depict differences in discharge for each study year in comparison with mean values for all observation period, allows to identify the pattern of discharge changes. In the calculation, ratio K was used: $K = \frac{Q_i}{Q_0}$ where: Q_i - discharge in year i; Q_0 – mean discharge for the entire period of observation. Using this approach, the integral curve is produced by summing these deviations $\sum(K-1)$. By integration of the deviations, the amplitude of the oscillations increases proportionally to the length of the period, with one-sign deviations in the row. The analyses of integral curves allow to identify precisely the significant change points of low-water and high-water discharge periods. High-water discharge periods are considered to be the years for which K > 1, and low-water flow periods are indicated by a K < 1.

The multivariate Mann-Kendall test (as described by Hirsch *et al.* 1982; Hirsch and Slack 1984) for monotone trends in time series of data grouped by sites was chosen for the determination of trends, as it is a relatively robust method concerning missing data, and it lacks strict requirements regarding data heteroscedasticity. The Mann-Kendall test was applied separately to each variable at each site, at a significance level of p<0.5. The trend was considered as statistically significant at the 5 % level if the test statistic was greater than 2 or less than -2 (Hirsch and Slack 1984).

RESULTS AND DISCUSSION

Changes in river discharge were determined using linear trend analysis, as it is a commonly used approach in the study of river discharge. Figure 1 and Table 2 shows that the discharge trends in the rivers of Latvia and the north-eastern part of the Baltic Sea are evident: the discharge has significantly increased for the Venta, Gauja, Bārta, Irbe, and Tulija rivers, but the changes are significant and increasing for all of the other studied rivers. It is also observed that river discharge is characterized by a stronger increase if the period of trend analyses for the last 50 years is taken.

An observation period of more than 150 years at the Meteorological Station Riga-University shows that, during the last century, the mean annual temperature has increased by about 0.8-1.4 °C, and the total annual precipitation by about 7.5 mm every year. Using moving average values (in this case with a step of 6 years), a good coherence is seen between the changes in annual precipitation at the Meteorological Station Rīga-University and the discharges of the largest and mid-sized rivers in the Baltic region (Daugava, Nemunas, Narva and Pärnu rivers), which flow into the eastern coast of the Baltic Sea (Figure1).

Table 2. Significance test for temporal changes of water discharge for rivers in Latvia*

River, sampling station	Period of observation	Normalised test statistic	Period of observation	Normalised test statistic
Daugava, Daugavpils	1905-2004	-1.16	1961-2004	2.41
Venta, Kuldīga	1905-2004	2.39	1961-2004	1.09
Lielupe, Mežotne	1920-2004	-0.91	1961-2004	1.94
Gauja, Sigulda	1939-2004	1.82	1961-2004	2.50
Salaca, Lagaste	1926-2004	1.07	1961-2004	2.79
Aiviekste, Lubāna	1959-1999	1.65	1961-2003	2.25
Dubna, Sīļi	1948-1998	1.57	1961-1999	3.00
Bārta, Dūkupji	1950-1999	2.35	1961-1999	2.53
Irbe, Vičaki	1955-1999	2.19	1961-1999	2.67
Tulija, Oļi			1961-2004	2.85

* - The trend can be considered as statistically significant at the 5 % level if the test statistics is greater than 2 or less than -2.

The Figure 1 also indicates the periods with low and high water levels, and the presence of regular cyclic processes. A close relationship between meteorological data and discharge can be found when studied for periods longer than 60 years.

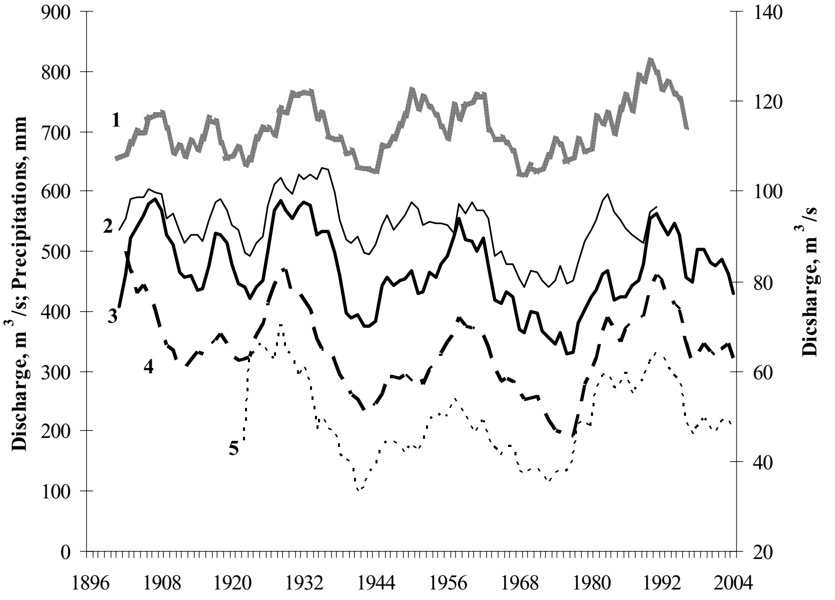

Figure 1. Long term change of mean annual discharge of the rivers in Baltic region and precipitation. 1 – precipitation (Station Rīga-University); 2 – the Nemunas River; 3 – the Daugava River; 4 – the Narva River; 5 – the Pärnu River. Data were levelled to a 6-year moving average.

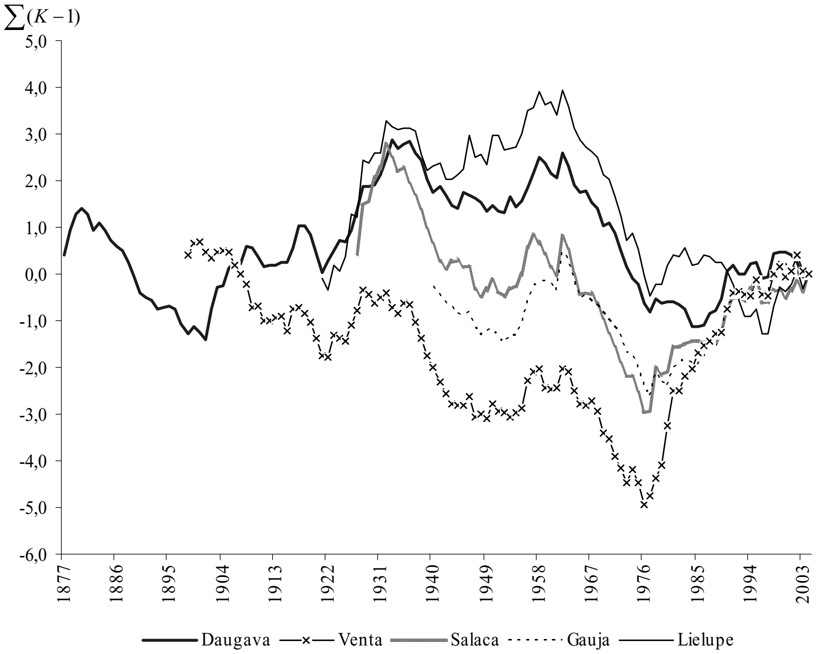

Figure 2. Normalized integral curves for coefficients of the annual runoff of rivers in Latvia.

The use of integral curves allows to identify oscillation patterns better. Figure 2 shows integral curves for water discharge in the five largest rivers in Latvia. Differences are seen between Lielupe and the other four large rivers in Latvia, and in all rivers there is an apparent difference between observations before and after 1920. For example, in the Lielupe River, water discharge decreased from 1986 to 2000, in contrast to the other rivers that showed stable increasing tendency. As it can be seen in Figure 3, in the year 1996 the water discharge reached the lowest value during the last ten years. The difference in flow patterns between the Lielupe River and other rivers in Latvia can be explained considering that the sampling station in Lielupe, is situated quite upstream (110 km) and thus can reflect more than 50 % of the total river discharge. The Lielupe River basin is moderately affected by melioration and by construction of various hydrotechnical constructions (dams, ponds, etc.). Agricultural activities also influence the water flow regime in this river.

Table 3. Changes of low and high discharge periods for the largest rivers in Latvia

Low discharge period	Years	Q_{mean}, m^3/s	K	High discharge period	Years	Q_{mean}, m^3/s	K
Daugava (1881-2004)							
1881-1901	21	401	0.87	1902-1908	7	595	1.29
1909-1921	13	442	0.96	1922-1936	15	549	1.19
1937-1952	16	419	0.90	1953-1958	6	555	1.20
1959-1985	27	401	0.87	1986-2004	19	490	1.06
Total, mean	*77*	*416*	*0.90*		*47*	*547*	*1.18*
Venta (1897-2004)							
1900-1923	24	60.2	0.92	1924-1930	7	72.1	1.10
1931-1949	19	57.0	0.87	1950-1959	10	69.9	1.07
1960-1977	18	57.1	0.88	1978-2002	25	79.1	1.21
Total, mean	*61*	*58.1*	*0.89*		*42*	*73.7*	*1.13*
Salaca (1927-2004)							
1933-1952	20	25.6	0.84	1927-1932	6	44.9	1.48
1963-1976	14	22.4	0.74	1953-1962	10	34.6	1.14
				1977-2004	28	33.9	1.11
Total, mean	*34*	*24.0*	*0.79*		*44*	*37.8*	*1.24*
Gauja (1940-2004)							
1940-1952	13	62.5	0.89	1953-1962	10	84.5	1.21
1963-1977	15	55.8	0.80	1978-2004	27	77.4	1.10
Total, mean	*28*	*59.2*	*0.84*		*37*	*81.0*	*1.15*
Lielupe (1921-2004)							
1933-1942	10	49.4	0.89	1921-1932	12	71.9	1.29
1963-1977	15	39.8	0.72	1943-1962	20	61.8	1.11
1984-1997	14	48.9	0.88	1978-1983	6	66.3	1.19
				1998-2004	7	66.8	1.18
Total, mean	*39*	*46.0*	*0.83*		*45*	*66.7*	*1.20*

The general patterns of the periodicity of water flow regime in several major rivers in Latvia are summarised in Table 3. For the last 100-125 years low discharge periods for rivers of Latvia are longer than high discharge periods and they last from a minimum of 10 years up to a maximum of 21-27 years. High discharge periods used to last from 10 years (6-8 years), however, during the last 30 years for the biggest rivers (except Lielupe) their prolongation can reach 20 to 27 years. Goudie (1992) described sinusoidal changes of river discharge in eastern Europe. Short-term fluctuations with mean duration 4-6 years have been previously found in Estonia and Finland (Hiltunen 1994). It is important to recognize that the assessment of factors driving the changes of river discharge is far beyond the aims of this article for basically these questions are part of global climate change problems. Long term changes of river discharge patterns can be directly related to changes in North Atlantic Oscillation (Figure 3). One can only guess the factors determining the oscillatory pattern of river discharge, nevertheless, it can urge to reconsider the conclusions based on short-term observations and also the conclusions drawn when analyzing river discharge changes only as a linear process.

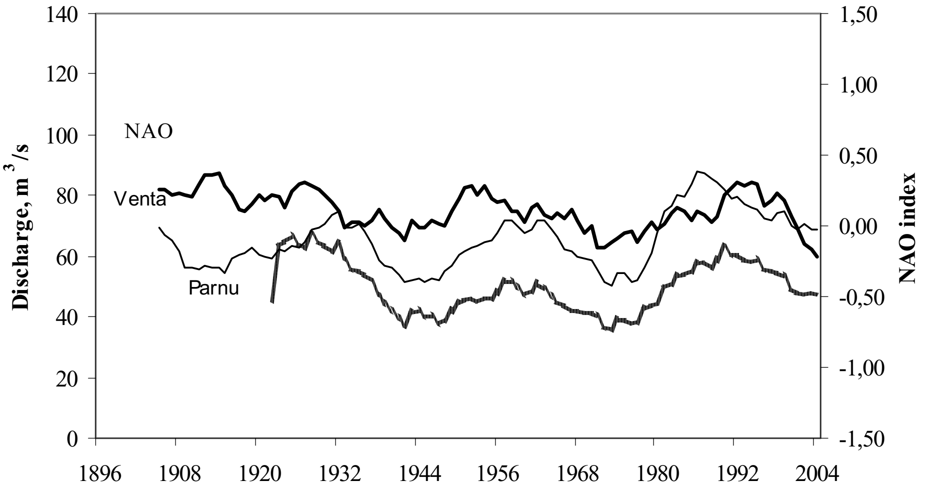

Figure 3. Long term changes of the Venta River and the Pärnu River discharge and North Atlantic oscillation index (data were levelled up to a 10-year moving average).

CONCLUSIONS

River discharge regime during the last century has been subjected to major changes, highly possible in relation to climate change. Well expressed regular changes of high-water and low-water periods are evident.

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Long-term discharge trends in Finland

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Keywords: discharge, trends, Finland, rivers, lake outlets

ABSTRACT

This paper presents long-term discharge trends and variability for thirteen time series including both rivers and lake outlets in Finland. These unregulated discharge time series were studied for the longest available period until year 2004 and for the period 1961-2004. The longest discharge time series date back to the mid-1800s. The aim of this study was to examine observed changes and variability in the Finnish discharge regime until so far. The discharge peak flow usually occurs in the south in April and in the north in June. In northern Finland the maximum flow of the year is always due to snow melt, but in the southern Finland summer, autumn and winter high flows are also possible. The Mann-Kendall trend test was applied to study changes in annual, monthly and seasonal mean discharges, maximum and minimum flows and in addition the date of peak flow. The trend analysis showed no changes in mean annual flow in general, but the seasonal distribution of streamflow has been shifted. Winter, spring and minimum discharges have increased at least in half of the observation sites. The magnitude of increase in winter and spring discharges was 2…10% per decade. The spring peak has moved earlier for the third of the studied sites with magnitude of 1…3 days per decade.

INTRODUCTION

Water resources are highly dependent of climatic conditions. Run-off regime is affected by both precipitation and temperature changes, as well as changes in radiation balances. Finland belongs to the so called humid zone. A typical feature in Finland is the abundance of water bodies, both lakes and rivers. The water situation may, however, greatly vary from year to year. Within a year, there is a considerable difference between the winter, when the precipitation is stored in the snow cover, and the summer, when a major part of the rainwater evaporates. In the long run, slightly more than half of the precipitation evaporates and little bit less than half flows into the seas from Finland. Discharge gauging is the most precise method of all water balance component measurements. Future climate scenarios predict both droughts and floods to be intensified due to greenhouse effect, therefore it is interesting to examine observed changes in the Finnish streamflow regime hitherto.

There are several earlier studies concerning long-term changes in Finnish discharge regime. Hyvärinen with his colleagues has carried out most of the discharge analysis done in Finland (Hyvärinen and Vehviläinen 1981, Hyvärinen 1988, Hyvärinen and Leppäjärvi 1989, Hyvärinen 1998, 2003). Kuusisto (1992) has also studied long-term runoff from Finland. Finnish streamflow records have also been included in the Nordic runoff studies conducted by Hisdal et al. (1995, 2003, 2004) and Roald (1998). Effects of climate change on water resources in Finland have been presented by e.g. Vehviläinen and Lohvansuu (1991), Hiltunen (1992, 1994), Vehviläinen and Huttunen (1997) just to mention a few.

DATA AND METHODS

The data consist of daily mean discharges for thirteen different gauges from the different parts of the country. Both rivers and lake outlets are included in this investigation. Discharges have been determined from water level records by the rating curve method. Many of the watersheds in Finland are regulated either for water power production or flood mitigation. All the studied sites are unregulated, but some changes (land uplift, changes in land use, bog drainage, forestry etc.) in the catchment during the years are unavoidable. Because there are so many regulated watersheds, an even distribution of studied discharge sites over the country was not possible. Many of the studied lake outlets are situated in the headwaters, since the lower water bodies are regulated. The longest discharge time series in this study date back to the mid-1800s. The study sites and their locations are presented Figure 1. The observation periods, upper catchments and lake percentages are presented in Table 1.

The data were analysed until the year 2004 for the longest available period, and in addition for the period 1961-2004. Trend analysis was applied to annual mean discharges (calendar year), monthly mean and seasonal mean discharges (winter: Dec-Jan-Feb, spring: Mar-Apr-May, summer Jun-Jul-Aug, and autumn: Sep-Oct-Nov), annual maximum and minimum flows and date of the peak flow (maximum). Trends were tested statistically with the non-parametric Mann-Kendall trend test. The level of 5% was used for the critical significance. Trend slope of the magnitude was calculated using a non-parametric Sen's slope estimator (Sen 1968).

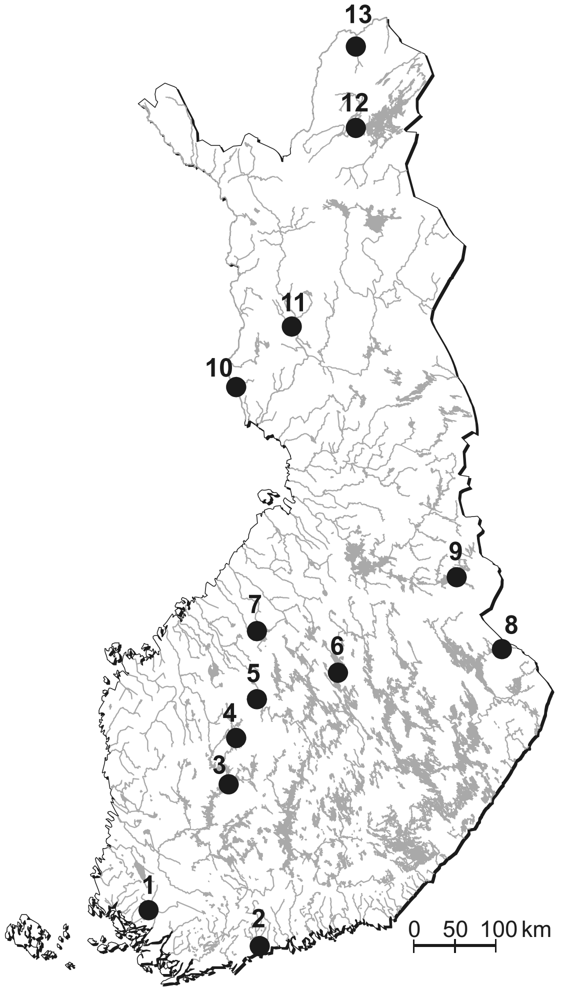

Figure 1. A map of the discharge gauging station locations used in this study

Table 1. A list of studied rivers and lake outlets including available time period, upper catchment (F) and lake percentage (L) of discharge point

Name	Observation period	F (km^2)	L (%)
1. Aurajoki, Hypöistenkoski (river)	1948-2004	351	0.0
2. Vantaanjoki, Oulunkylä (river)	1937-2004	1620	2.8
3. Muroleenkoski – outlet (lake)	1863-2004	6102	12.2
4. Kitusjärvi – outlet (lake)	1911-2004	546	9.6
5. Pääjärvi – outlet (lake)	1911-2004	1214	7.1
6. Nilakka Äyskoski (lake)	1896-2004	2157	17.9

7. Lestijärvi - outlet (lake)	1921-2004	363	21.1
8. Ruunaa – outlet (lake)	1931-2004	6259	13.7
9. Lentua - outlet (lake)	1911-2004	2045	12.7
10. Tornionjoki, Karunki (river)	1911-2004	39010	4.7
11. Ounasjoki, Marraskoski (river)	1919-2004	12303	2.6
12. Juutuanjoki, Saukkoniva (river)	1921-2004	5160	4.7
13. Utsjoki , Patoniva (river)	1963-2004	1520	2.6

RESULTS

The annual peak flow usually occurs in southern coast in April and in northern Lapland in the turn of May and June. In northern Finland maximum annual flow is always due to snow melt, but in the southern Finland summer, autumn and winter annual maximum flows due to high rainfall are also possible. In the north the minimum flow of the year is recorded in the winter, but in the south both winter and summer flow minima are common.

There is a great variation of discharge from year to year, and especially monthly mean discharges differ greatly between the years. The variation percentage of annual mean discharge ranged from 19 to 37%. It was highest in the southern river sites with a small lake percentage and a small area of the catchment. Lowest variations were recorded in northern Finland. The highest variation percentage of the monthly discharges, 220% was for February in the river Aurajoki.

The driest year has been at most of the sites either 1941 or 1942. The wettest year was not so evident as the drought of 1941-1942, on the contrary it varied between the sites. At many places the year 1981 was a rather wet one. The ratio between the wettest and the driest year discharges varied from three to six. The average ratio between HQ (annual maximum flow) and MQ (annual mean flow) of each year varied from 2- to 4-fold at lake sites and from 6- to 16-fold at river sites. The ratio is highly dependent on the lake percentage; if the percentage is low, the ratio is high and vice versa.

Statistically significant trends in streamflow for the longest possible period until 2004 and for the period 1961-2004 were studied. Eleven of thirteen sites (85%) had at least one trend detected. There were a larger number of statistically significant trends for the whole observation period available than for the period 1961-2004. There were no trends for the annual mean flow in general, only one site (river Tornionjoki) had statistically significant trend for increased discharges. Neither had high flows any long-term changes. The biggest change has happened in the seasonal distribution of flow. The spring peak has moved earlier, statistically significantly at one third of the observation sites. The magnitude of trend for the timing of the peak was 1…3 days per decade. Winter and spring discharges have increased at most sites. 69% of the time series had significant increase of discharge for spring months and 49% for winter months (at least for one month). The minimum flow has increased at 46% of the sites. The magnitudes of discharge increases were typically 2…10% of the mean flow (of month or season) per decade. The summer flows had increased only for 15% of the sites. In addition, one to two of the time series had negative trends for a few winter, spring or summer mean monthly discharges. Basically, no statistically significant trends in autumn flows were found. Time series of the mean annual discharge and the mean spring (MAM) discharge for different stations are presented in Figures 2 and 3. In Table 2, the summary of statistically significant seasonal trends is shown. Positive trends in winter discharge can be explained by milder winters during the last decades. The increased spring discharge is due to earlier spring peaks; the shift in the peak timing has increased discharges.

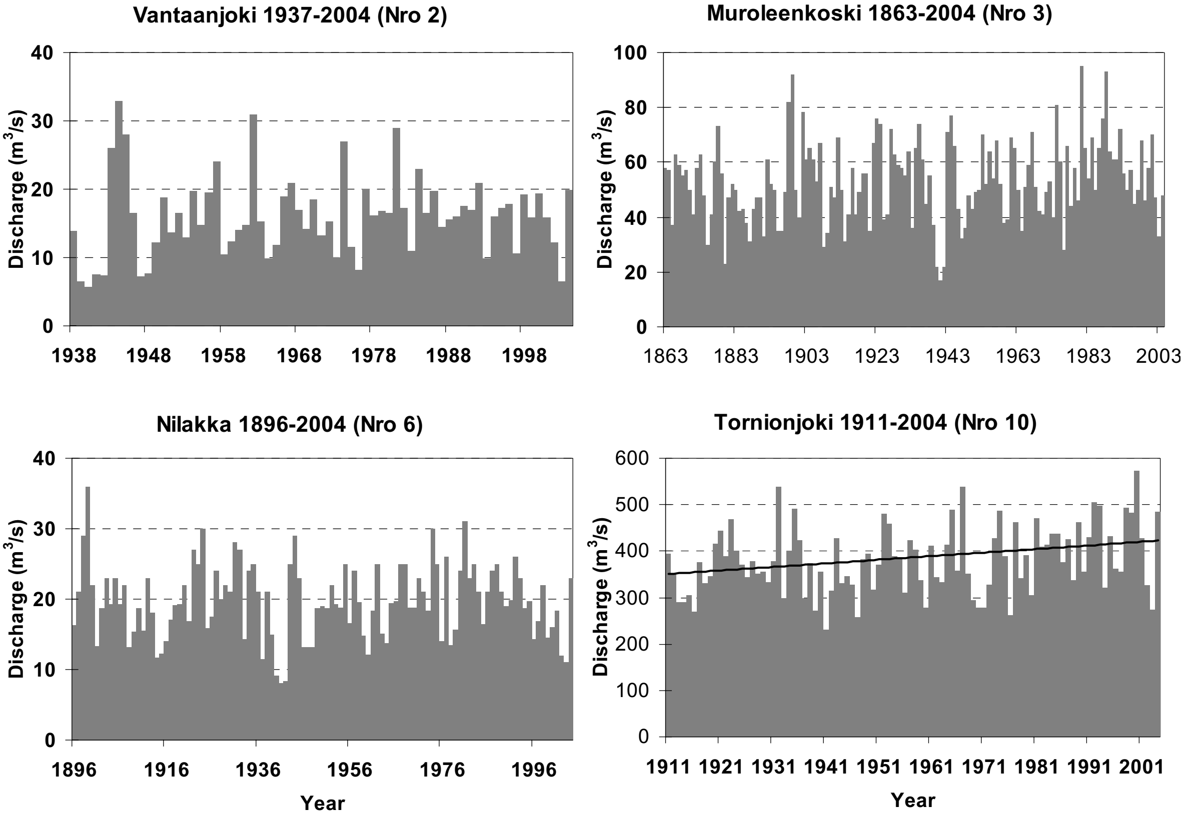

Figure 2. Mean annual (MQ) discharge (m3/s) for four different discharge gauges

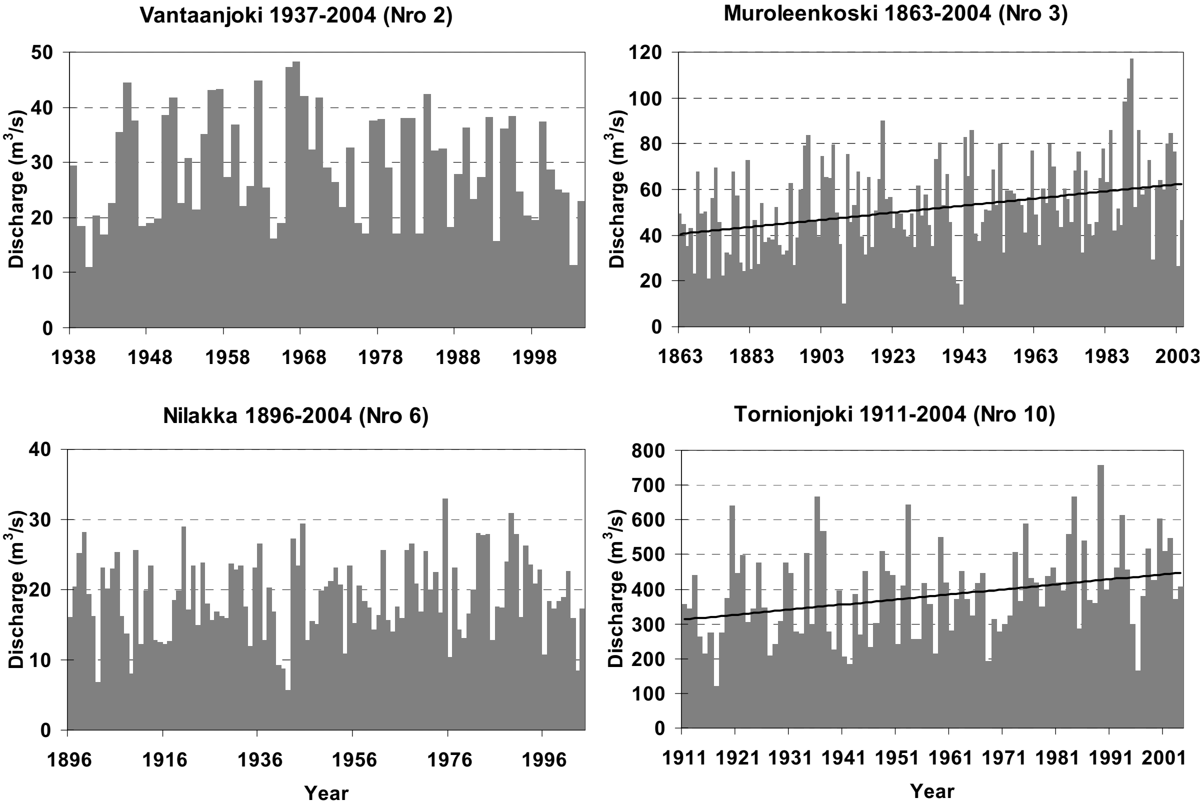

Figure 3. Mean spring (MAM) discharge (m^3/s) for four different discharge gauges

Table 2. Summary of statistically significant seasonal trends, percentage of all studied sites (13 sites)

	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)
Positive trend	31%	54%	15%	0%
Negative trend	0%	0%	0%	0%

COMPARISON WITH OTHER STUDIES

There are a number of earlier studies concerning long-term changes in runoff in Finland and in the Nordic countries. Anterior studies of long-term changes in runoff or discharge regime have shown quite similar patterns as this study. The increase of winter discharges in southern and central Finland was presented first by Hyvärinen and Vehviläinen (1980). Later observations and analyses confirmed these findings (Hyvärinen 1988, Hyvärinen and Leppäjärvi 1989, Hiltunen 1994 and Hyvärinen 1998, 2003). The Nordic studies of trends in runoff regime have revealed considerable differences in different parts of Fennoscandia (Hisdal et al. 1995, 2003, 2004 and Roald 1998). Mean annual discharges have been increased especially in some regions in Denmark and Sweden. Positive trends have also been found for Norway and Finland depending on the chosen time period (Hisdal et al. 2004). For the period 1941-2002 statistically significant trends are found for Finland probably because the first year of time period (1941) was the driest ever observed at many places in Finland. In Iceland, annual values of discharge do not show clear trends (Jónsdottir 2005). In Karelia, Northwest Russia, the river runoff has decreased during the 20th century (Filatov 2005).

Discharges are naturally highly dependent of precipitation and evaporation. Long-term changes have not been detected for the precipitation time series in Finland (Tuomenvirta 2004), although in the other Nordic countries (Sweden, Norway, Denmark, Iceland) increase has been observed (Hisdal et al. 2003, Jónsdottir et al. 2005). In Karelia, Northwest Russia precipitation has been increased during the 20th century (Filatov et al. 2005). The evaporation time series begin mainly in the late 1950s in Finland, thus such long time series as precipitation and discharge records, are not available for the Class A Pan evaporation. However, for the period 1961-1990 no trends were reported by Järvinen and Kuusisto (1995). Neither precipitation nor evaporation show remarkable long-term trends in Finland. Regardless, the changes in the streamflow have been observed in Finland. However, the annual mean flow in unregulated streams has not changed in Finland in general. The main issue is the change in the seasonal distribution of discharge regime.

DISCUSSION AND CONCLUSIONS

Thirteen Finnish discharge time series of unregulated rivers and lake outlets were examined in this study. The timing of high flow in the rivers varies from April to June from the south to north, respectively. The low flows are recorded in the north in the winter and in the south typically in wintertime or in summertime. Typical variation of annual mean discharge was 20…40%. It was highest in southern river sites with a small lake percentage and a small area of the catchment. Lowest variations were in northern Finland. The ratio between annual high flow and annual mean flow varied from two- to four-fold in lake outlets and from six- to sixteen-fold in rivers.

Trends of time series were analysed in order to find changes in the historical records. Mean annual, monthly and seasonal discharge trends as well as changes for the extreme values were calculated by the non-parametrical Mann-Kendall trend test. Mean annual flows showed no changes, but the seasonal distribution of flow has changed in most places investigated in this study. The spring peak has moved earlier for the third of the sites. The change has been 1…3 days per decade. Trend analysis showed that the winter, spring and minimum discharges have increased at least half of the observation sites. The magnitude of observed increase in the monthly or seasonal discharge was typically 2…10% per decade. Positive trends in winter discharge can be explained by milder winters with increased winter precipitation during the last decades. The increased spring discharge is due to earlier spring peaks caused by warming during the spring time; the shift to earlier peak flows has increased discharges. There were no statistically significant changes in autumn streamflow in general.

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Tap Runs Dry: Managing urban water supply now and in the future in Canada

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ABSTRACT

The recently released Intergovernmental Panel on Climate Change (IPCC) Working Group I report has concluded that increased risk of drought will likely occur under future climate change. *Urban drought* (a type of socioeconomic drought) occurs when there is an adverse change in the urban water balance between supply and use. Recent events such as the water crisis that occurred in Tofino, British Columbia in 2006 highlights how the viability of water supplies in normally water-rich Canadian communities can be negatively impacted by severe drought conditions.

The "Tap Runs Dry" project identifies and recommends some adaptive options that could be used to extend the coping range and decrease the vulnerability of Canadian municipalities to future droughts and water supply shortages under climate change. This project focuses on evaluating temporal changes in urban drought impacts and adaptive responses. Southern Ontario, which contains approximately one-third of Canada's population of 32 million, was chosen as the study region. Responses taken by water management organizations in some of Southern Ontario's larger municipalities to deal with water shortages are documented for four severe droughts that occurred from 1988 to 2005.

An inventory of water-related adaptations was created to identify both planned and reactive as well as short-term and long-term measures that were used as the droughts progressed. Typical responses to urban drought are to either decrease water demand and/or increase water supply. The vulnerability of communities to urban drought is affected by the water source used (i.e., Great Lakes, groundwater, river, combination of water sources), and other factors such as population growth, suburban sprawl, local capacity, and changing water demands by all users.

Typical drought risk management and responses at the local level include monitoring of drought conditions and municipal water supplies, drought planning and preparedness (Ontario Low Water Response), and water conservation programs (components include staged non-essential water use, by-law enforcement and appropriate public education initiatives). Sustainable long-term water supply plans (e.g., 50 years) should include provisions for projected climate change impacts on hydrology, water supply, and drought. Several long-term water supply plans for Southern Ontario are assessed.

Some challenges regarding the selection of appropriate indicators of urban drought impacts are identified. The utility of programs such as the OLWR, which uses specific thresholds of precipitation and streamflow deficits, to help communities cope with drought-related municipal water supply impacts and urban drought conditions are discussed.

INTRODUCTION

Canada is considered a country with abundant water resources. However, recent events such as the water crisis that occurred in Tofino, British Columbia in 2006 showed that the viability of water supplies in normally water-rich Canadian communities can be negatively impacted by severe drought conditions. In general, though, decision-makers in urban areas are reluctant to make policies to reduce the risk of drought-related water shortages until an actual prolonged drought occurs. The "Tap Runs Dry" project aims to assess and document the lessons learned by urban communities during for four severe droughts that occurred from 1988 to 2005 in southern Ontario. The specific project objectives are: 1) Evaluate the impacts of past severe droughts and document the adaptive responses to drought conditions in southern Ontario for several case study communities; and 2) Identify, and highlight effective adaptive options that limited damages, and increased the capacity of the communities to cope with past severe drought conditions.

METHODS

The project consisted of four main components: drought hazard analysis, literature review, documentation of historical adaptations to past droughts, and vulnerability mapping. Highlights from the drought hazard analysis and documentation of historical drought adaptations are presented.

Study location

The Regional Municipality (RM) of York is located directly north of the City of Toronto (Figure 2). It is one of five municipal cases, in four watersheds, that are being investigated. The current population (892,712 in 2006) has more than doubled since 1986 (364,000) (RM of York, 2005a, 46; Statistics Canada, 2006). United Utilities Canada (UUC) forecasts the Region will surpass 1.4 million people by 2036 (UUC, 2004).

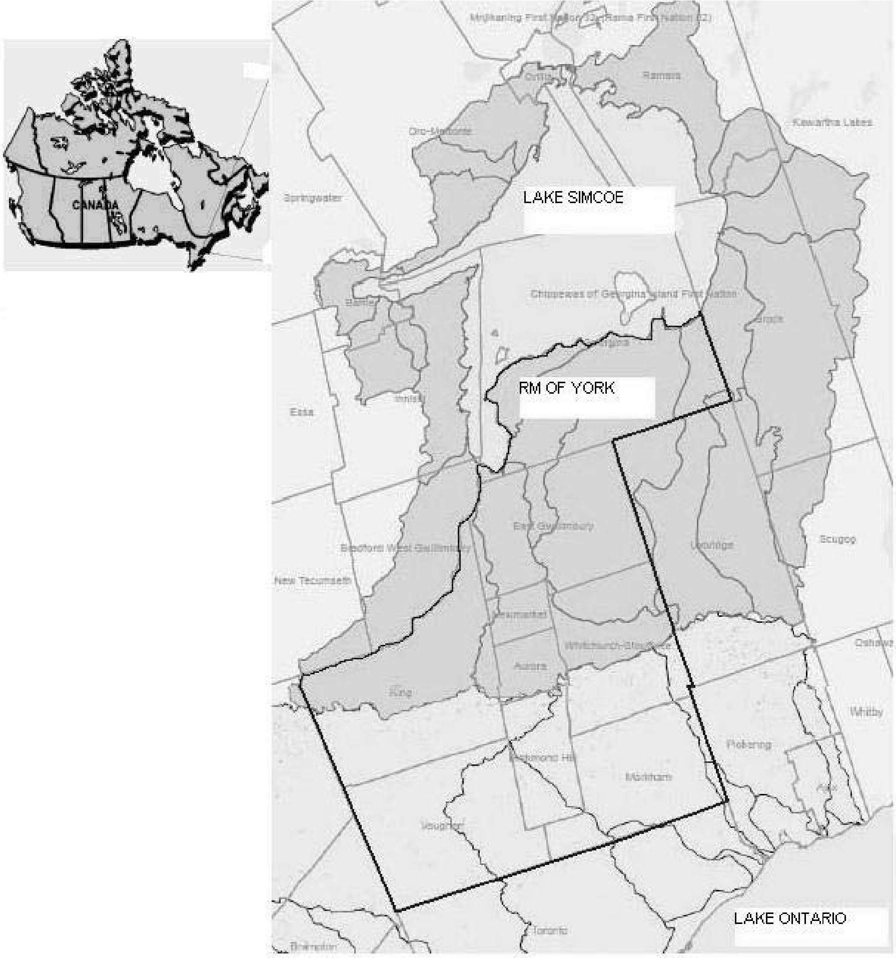

Figure 2. Lake water sources and conservation authorities in the study area

The water supplied for this municipality comes from a variety of sources. The urban areas in the southern municipalities of Markham, Richmond Hill and Vaughan rely on treated water from Lake

Ontario, treated and provided by the City of Toronto and Peel Region. Kleinburg and other smaller communities in central and northern York Region, receive water from groundwater by means of a system of production wells operated by the Region. In addition, surface water from Lake Ontario supplements the water supply for Aurora and Newmarket. In rural areas, individual private wells provide water supply. The communities of Keswick and Sutton (in Georgina) obtain water from Lake Simcoe via York Region's water treatment plants.

The RM of York sells water in bulk to its area municipalities and maintains responsibility for production, treatment, storage and the regional distribution network. Area municipalities are responsible for pricing and distributing water to consumers, in addition to enforcing water use by-laws (RM of York, TWC, 2002; RM of York, 2006a). Conservation Authorities (CAs) are local, watershed management agencies, created under provincial legislation, to deliver services (e.g, planning, development permitting) and programs related to the protection and management of water and other natural resources. York Region comprises portions of several watersheds. The Lake Simcoe Region Conservation Authority (LSRCA) is responsible for the watersheds in the northern portion, which includes most of the groundwater-dependent communities and those reliant on Lake Simcoe, and the Toronto Region Conservation Authority (TRCA) manages the watersheds in the more populous southern part.

Drought hazard analysis

Although "lack of moisture" is basic to all definitions of drought, the actual definitions and quantification of drought vary between individuals, depending on how the water shortages impact on their lives. There is no one universal drought index or indicator that is used to quantify drought and compare the severity of droughts. However, there are several indices that are recognized within the drought monitoring and water resource community as being useful in defining the severity and spatial coverage of the drought.

Within Ontario, the province's "Low Water Response Plan" (OLWR) was developed in 1999, implemented in 2000, revised in 2003 and continues to undergo periodic review (OMNR *et al.,* 2003) to ensure that provincial and local authorities are advised of and prepared to take action in the event of low water conditions in provincial watersheds. Three water level conditions, Levels 1-3, are defined using specific precipitation and streamflow indicators. Threshold levels for cumulative precipitation departure from average are defined over specific time periods (i.e. 1, 3, 18 months). The streamflow indicator examines specific departure levels of the monthly streamflow from average summer flow. However, unlike traditional drought indicators, each of the three OLWR Level Conditions is considered to also be an indicator of potential water supply problems and is subsequently linked to specific water management response actions when an OLWR Level Condition has been declared

The OLWR precipitation and streamflow criteria were calculated for climate stations within the selected Ontario case study regions. Several standard meteorological precipitation drought indicators were also computed, including Precipitation Departure from Normal, Consecutive Dry Days, Consecutive Dry Years (based on Percentiles), Precipitation Deciles and Standardized Precipitation Index. Temperature Departure from Normal and Number of Hot Days were also calculated. All of the indicators were evaluated over the selected climate station periods of record from the early 1900s (where available) through 2005, with a particular emphasis of comparing the severity of recent droughts to historical droughts of the 1930s, 1950s and 1960s. Gridded Standardized Precipitation Index data was also mapped for recent drought years to determine the spatial extent, severity and duration of the droughts in southern Ontario.

RESULTS

The most common responses to urban drought are to either to decrease water demand (i.e., improve water use efficiency) and/or to increase water supply. This section assesses the evolution of adaptation options and drought planning and preparedness in York Region.

Drought planning and preparedness

At present, there is no formal drought contingency plan established for York Region. The OLWR, has highlighted the need for collaboration among local area stakeholders to improve drought monitoring and coordinate response. York Region monitors well levels and reservoir capacity closely and is responsible for advising area municipalities when supplies are being depleted, through a staged notification protocol that calls for progressively stronger water restrictions. Area municipalities are responsible for implementing the necessary restrictions. The York Region Water Response Team (WRTY), formed under the OLWR in 2001, allows for local drought information sharing between provincial ministries (Natural Resources, Environment), CAs (LSRCA and TRCA), York Region and some area municipalities, and an association of golf courses. Although regular meetings have occurred since its formation in 2001, the WRTY has so far played a limited role in drought planning, partially due to short-term, sporadic funding and the voluntary status of members (T Hogenbirk 2007, pers. comm., 8 May).

Unfortunately streamflow indicators used by the Ontario Ministry of Natural Resources (OMNR) may not always reflect local drought conditions, especially in the headwaters, where there are few hydrometric gauges (WRTY, 2001). For example, water managers in the TRCA have mapped baseflow in their watersheds, as OMNR streamflow indicators are not adequate in representing the local hydrological response (D Haley, 2005, pers. comm., 18 May). Baseflow indicators have not been identified in the current OLWR plan (OMNR *et al.,* 2003). The TRCA has developed a more comprehensive Low Flow Program, which monitors 1200 locations and takes into consideration baseline conditions for baseflows (TRCA, 2004). This type of monitoring program is beyond the financial capacity of most CAs (D Haley 2005 pers. comm., 18 May). Conversely, in the LSRCA's watersheds, the Holland River streamflow gauge is considered adequate for monitoring drought conditions as this is a particularly sensitive river, and is usually one of the first watersheds to experience low flows (T Hogenbirk 2007, pers. comm., 8 May).

Drought impacts

For the study, four past historical drought periods were examined in York Region. Table 1 outlines some of the impacts on the municipal water supply and use, according to newspaper articles, press releases and key informant interviews. Figure 3 indicates dry summers were experienced in 1988, 1997 to 1999, 2001 to 2002. Municipal water managers in the Greater Toronto Area (GTA) generally consider it to be a critical water shortage when reservoirs drop below 20% capacity, which begins to affect the supplies available for emergency water uses and fire response (B Macgregor 1998, pers. comm., 14 August; L. Radman*,* 2006, pers. comm., 29 November). There appears to be only one instance (in the wet summer of 2006) where reservoirs dropped below 20%.

It is important to note that hot and dry weather is often accompanied by other stressors which increase the severity of drought impacts. For example, in the summer of 1997, a power outage disabled pumps in Newmarket, further hindering efforts to supply water to residents. Another important factor that exacerbates urban drought is housing. New development in metro Toronto and York Region significantly increases water demands, primarily due to the watering of newly laid sod (Toronto Star, 1988a). It is fairly typical for summer water use to increase to 2 to 4 times the daily average use (RM of York, TWC, 2002; York Region Health Services Department, 2005). Increasing per capita water use in estate residential communities with automated lawn irrigation (e.g., Kleinburg) will likely increase the vulnerability of residents to weather-related water shortage (T. McLean 2007, pers. comm., 20 December).

Table 1. Selected impacts of drought on York Region water supplies and use.

Year	Impacts on municipal water storage and use	Drought condition
1988	• June 13 to 16: Vaughan reservoirs reached zero levels in the communities of Maple (North and South Maple Reservoirs) and Woodbridge (East and West Wood-	Maximum temperatures of >=30C were recorded on up to 37 days from late May-mid August. Below-

	bridge Elevated Tanks) (Koshida et al., 1999). • July 7: Lack of pressure causes water loss in North York (in Metro Toronto) highrises (Toronto Star, 1988b). Hot, dry weather and a lack of precipitation is cited as the main cause of the water shortage (Toronto Star, 1988b).	normal precipitation in May and June 1988, winter 1987 and spring 1988.
1997	• Mid-July to August 13: Unusually heavy pumping from municipal wells in Central York Region caused by a lack of rainfall and increased demands for lawn watering (RM of York, 1997c).	Abnormally dry and warmer than normal conditions affected southern Ontario from mid-1997 through early April 2000.
2001	• July 30 to August 20: Low reservoir levels in southern York Region due to exceptionally high water demands (RM of York, 2001a). • July 30 to Sept 4: Low reservoir levels also occurred in central York Region for a longer period. Groundwater supplies took more time to recharge to acceptable levels capable of refilling reservoirs (RM of York, 2001b).	Temperatures exceeded 30C for nine days in early August, while July to September rainfall was well below normal.
2002	• July 17 to August 6: High demand is straining water supplies. Reservoirs cannot be maintained at 65% of capacity in the groundwater-dependent communities of Kleinburg, central York Region, King and Whichurch-Stouffville. The Region is having difficulty maintaining reservoirs reliant on lake-based sources (in south York Region and Georgina) at 75% capacity (RM of York, 2002c; 2002d).	Up to 33 days in southern York region recorded high temperatures of 30C or more. In addition to the heat, rainfall was well below normal from late July through mid-September.
2005	• June 10 to 14: Reservoir levels dropped below 65% of capacity in central York Region and Kleinburg (in the City of Vaughan) and below 50% in Richmond Hill (RM of York, 2005c; 2005d). • July 11 to August 18: Water storage reservoirs supplying water to the community of Kleinburg could not be maintained at 65% of capacity (RM of York, 2005e; 2005f).	Maximum temperatures of >=30C were recorded on up to 40 days in June through August in southern York region. Very dry conditions, occurred with precipitation well below normal from May to July.

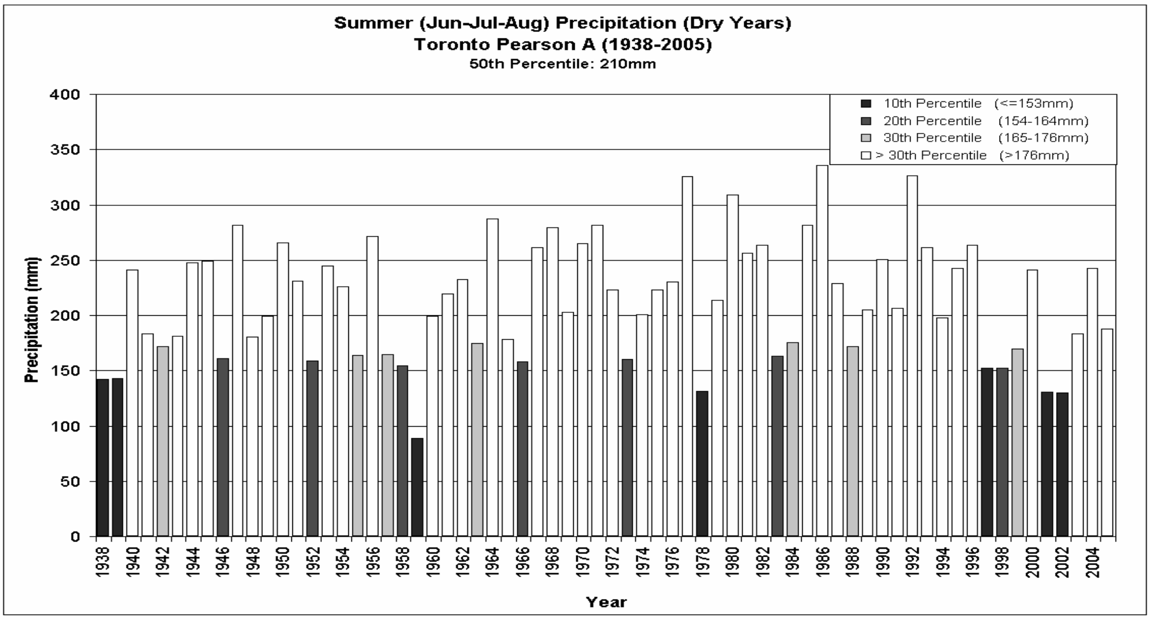

Figure 3: Summer precipitation deciles for Toronto Pearson Climate Station (1938 to 2005).

Evolution of adaptations

Demand management measures were most commonly used to deal with drought. Residential water use, especially lawn watering and pool filling, accounts for the largest portion of urban water use (RM of York, TWC, 2002; Atwood, 2004). During drought periods, mandatory restrictions supported with local by-laws were implemented in several area municipalities. Prior to 1997, water use restrictions were generally implemented in a reactive and ad hoc manner. Mandatory water restrictions were enacted in southern York Region municipalities, including lawn watering bans in Newmarket and Aurora, during the summers of 1988 and 1997 (Toronto Star, 1988b; 1997). Short-term supply management measures were implemented in some areas. For example, in 1988, Maple reservoir was filled by using fire trucks. By 1997, all area municipalities had developed and were implementing permanent by-laws governing summer water use. These by-laws restricted water use to the early morning or evening hours (when evaporation and other water demands are lower) and included provisions for total bans on outdoor water use when necessary (RM of York, 1997a).

Consistency and enforcement of water use by-laws is a major challenge and has been identified by other municipal water managers (e.g., City of Guelph) (P Busatto 2006, pers. comm. 6 December). A committee recommended in 2002 that municipal by-laws be revised for the following reasons: 1) to allow a staged implementation of increasing levels of restrictions, based on water supply availability; 2) to ensure by-laws outlined consistent restrictions, penalties, enforcement and exemptions for all area municipalities. The report recommended a protocol be developed and managed for implementing the staged/hierarchical restrictions (RM of York, TWC, 2002). The consolidated by-law, has three stages of restrictions: 1) an outdoor water use advisory; 2) an outdoor water use ban, 3) outdoor water use ban plus restrictions on other non-essential uses (RM of York, TWC, 2002). The threshold levels for issuing advisories or restrictions are much higher than the 20% reservoir capacity emergency threshold, which likely leads to more proactive responses. As a general condition, current summer water use by-laws, restricting water outdoor water uses (pool filling, car washing and lawn watering) to every other day at certain times, are relatively consistent across all nine area municipalities (RM of York, 2006b). In addition, maximum fines of $5,000.00 may act as a deterrent (RM of York, 2006b). The protocol of staged response seems to have improved drought mitigation in the York Region, and even attempts to link to the OLWR program for Stage 3 restrictions (20% mandatory reduction in water use); however, the plan lacks drought triggers related to climate variables or indicators.

The Region has implemented longer-term strategies to encourage water conservation through its Water for Tomorrow program. Initiated in 1998, the program has several components, including a residential/commercial retrofit program, water audits for industry and institutions, leak detection and repair, and public education, including summer water use reduction campaigns (UUC, 2004; Brooks, 2007). For example, the Region offered free landscaping assessments to reduce water needs and free irrigation system assessments and retrofits for the community of Kleinburg. The Water for Tomorrow program has already surpassed its original goal of conserving 19.8 ML of water per day, currently achieving 20.33 ML of sustained water savings per average day (Brooks, 2007). These savings are supported by a maintenance budget, similar to that associated with physical infrastructure. The Region anticipates saving 33 ML of water/day by 2008, which will reduce the need to build as much new infrastructure to service this demand (UUC, 2004).

Increasing water supply through the continuous expansion of water infrastructure and diversifying water sources (integrating with other water systems) are two other strategies for ensuring water needs are met in the RM of York (UUC, 2004). Communities reliant on the aquifer are considered more vulnerable than those withdrawing water from the larger lake-based sources, which are capable of responding to increased demand more readily because of the large volume of stored water available at all times for pumping (RM of York, 2002b). In 2002, the Region integrated some water pumped from the City of Toronto system into the municipal supply in Aurora and Newmarket, which were formerly entirely groundwater dependent (RM of York, 2002a; 2006a). Water from the RM of Peel was introduced to the York Water System in the fall of 2005 (RM of York, 2005b). The RM of York has agreements with the City of Toronto and Peel Region for continuous increases in water supply until 2031. Although this expansion has been motivated largely by meeting the growing water demands associated with population growth, another benefit is the increase in system capacity to satisfy peak summer demands (UUC, 2004; T. McLean 2007, pers. comm., 20 December).

DISCUSSION AND CONCLUSIONS

Compared to other case study locations, York Region and its area municipalities seem to be generally prepared to deal with droughts. The Region's high levels of population growth and employment, while a tremendous challenge for ensuring water demands are met, contributes to the financial capacity to institute long-term conservation programs (Water for Tomorrow) and expand of water resources infrastructure, storage and new sources of supply. For the most part, drought is not considered a major threat/hazard- in the same line as flooding for example - so the response to it tends to be reactionary.

This has improved somewhat since the introduction of the OLWR program, which raised the profile of drought in the province. After the creation of the WRTY, York Region proposed the harmonization of area municipal water use by-laws and a staged protocol of impacts and associated responses. This has led to more proactive monitoring of reservoir levels and better communication throughout the Region in recent years. In the long-term, permanent summer by-laws reduce the needs for municipalities to increase water production capacity (Brooks, 2007).

The WRTY has issued some media advisories on drought conditions, but presently has a low profile in the region. Part of the problem is the lack of reliable funding, and the fact that members are occupied in other jobs and have little time to devote to voluntary initiatives. Although few responses have implemented so far, having this group in place and meeting on a regular basis increases information sharing and the capacity to respond to future droughts. In addition, it provides important links between impacts and adaptations, even if these have yet to be implemented.

Climate change is not currently a component of long term water supply planning in the RM of York. Given there are no plans to limit growth, it is critical that the Region begin to consider how cumulative stressors may influence the vulnerability of urban water supplies. Although, it does not address drought directly, the Water for Tomorrow program is a good example of a proactive strategy which can help reduce vulnerability to drought.

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Changes of the dry period runoff in Lithuanian

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ABSTRACT

Climate change (increasing of air temperature and decreasing of summer precipitation) has impact on drought characteristics of rivers runoff (frequency, duration and discharge) in many countries. More intensive droughts could negatively affect sectors of water supply (energy and water abstraction) and sustainable state of rivers (water quality). Increased water temperature and reduced dissolved oxygen level could affect the state of water body ecosystems. The drought data series were defined as a series of the 30-day minimum discharge for the summer low flow period. In Lithuania the 30-day minimum discharge in winter period is larger than in summer period on average 1.2 - 2.9 times. Therefore the analysis of summer droughts has been carried out. The temporal and spatial distribution of drought characteristics is uneven in Lithuanian rivers. The 30-day minimum discharges of the rivers are different in 3 hydrological regions of Lithuania (Western, South-Eastern and Middle Lithuania). In Western Lithuania the runoff of the most dry 30-day summer period varies from 0.4 to 2.5 l/s· km², in the Middle Lithuania – from 0.1 to 1.7 l/s· km² and in the South-Eastern Lithuania - from 1.7 to 5.6 l/s· km². Research objectives: 1) analysis of long time series of the 30-day minimum discharge and its timing for 3 Lithuanian hydrological regions and the Nemunas river, 2) investigation of natural cycles and trends in the time series of the 30-day minimum discharge of rivers. This study is part of a Nordic cooperative research project "Climate and Energy Systems" (CES) where the statistical analysis of long time runoff series has an important role.

INTRODUCTION

Researchers worldwide and in Europe give a great deal of attention to climate change. It is emphasized that main variations of climate elements – atmosphere circulation, air temperature, precipitation, snow and ice cover have been occurring since the sixth decade of the last century (Arnell, 1996; Bergstrom, et al., 2001; Frisk, et al., 2002; Hisdal, et al., 2003; Reihan, et al., 2006). Such trends are recorded by Lithuanian climatologists as well (Bukantis, 2002) and they forecast variations of different climate indicators – rise of air temperature, increase of precipitation during the cold period of the year, decrease of days with snow cover, increase of droughts during summer months and increase of frequency of extreme air phenomena.

It is important to analyze the characteristics of drought runoff. Low flow of summer period, particularly during dry year, causes critical situations by providing consumers with water, does not ensure possibilities of water purification, and disturbs the natural existence of water ecosystems. In Lithuanian rivers after the end of spring flood, a rather long period of drought begins. It finishes with the beginning of autumn rainfalls. Other period of drought in rivers exists during winter season between autumn rainfalls and spring flood. In Lithuanian rivers the summer-autumn drought period is significantly deeper and longer. On average in the whole Lithuania it begins at the end of April – at the beginning of May.

Lithuania according different types of rivers feeding and hydrological regime is divided into three hydrological districts: Western, Middle and Southeastern. According to annual observation data in Western and Middle Lithuanian rivers, the summer-autumn drought period varied in the interval of 80-207 days of year, in Southeastern Lithuanian rivers - in the interval of 95-212 days, whereas in the biggest rivers Nemunas and Nėris - in the interval of 45-218 days (Gailiusis, 2001). The drought period of winter season is much shorter. It usually begins at the end of December and continues till the beginning of February-March. The shortest winter drought periods are characteristic of Western Lithuanian rivers, their duration is 50-70 days. Though drought periods of winter seasons are twice shorter than that of summer-autumn, their average 30-day minimum discharges are larger: in Western Lithuanian rivers ~ 2.8 times, in Middle Lithuanian rivers ~ 1.9 times, in Southeastern Lithuanian rivers ~ 1.2 times. Thus form ecological point of view that summer-autumn drought periods are significantly more dangerous. The runoff of the most dry 30-day summer period in Western Lithuania is 0.4-2.5 $l/s{\cdot}km^2$, in Middle Lithuania 0.1-1.7 $l/s{\cdot}km^2$ and in Southeastern Lithuania 1.7-4.7 $l/s{\cdot}km^2$.

The task of this study is to investigate trends and cycles, compounded of the dry and wet periods, in the long minimal runoff series of Lithuanian rivers. The cycles of 25-28 years are investigated in the rivers of Western, Middle and Southeastern regions, the minimal runoff of the longest time-series of the Nemunas river is analyzed as well.

METHODS

The drought data series were defined as a series of the 30-day minimum discharge (Q_{30}) for the summer low flow period. It was evident that the daily minimum flow data series contained many casual errors. Therefore 30-day minimum discharge averages were used for the minimum flow regime analysis in order to obtain more reliable calculation results. Representative historical daily data series from 30 gauging stations are used for the calculation of cycles compounded of wet and dry periods in the river's low runoff (10 stations from Western, 10 – from Middle and 10 – from Southeaster region). The long time series of daily discharges of the Nemunas river near Smalininkai has been used for calculation of 30-day minimum discharge since 1812.

The method of integrated curves of modular discharge coefficients is used for the analysis of low runoff variations. An analysis of the integrated curves of Q_{30} is used to describe the wet and dry periods in the rivers' low runoff. The integrated curve ($\sum_{i=1}^{n}(k_i - 1)$) is the sum of variations of modular coefficients from the average value. Modular coefficient $K_i = Q_i / \bar{Q}$. The integrated curves with 5-year moving average point up the dry and wet periods of rivers runoff. The Mann-Kendall test with a 5% significance level, recommended by the WMO (1988), was applied for the data series trend analysis. In addition, positive and negative trends that are significant at the 30% level were applied.

RESULTS

The drought period and its characteristics (duration, average discharge and runoff volume) are river's hydrological regime indicators, usually one characteristic of this period is used for research – the average runoff (Q_{30}) of 30 driest days in course for the summer low flow period. The advantage of discharge Q_{30} in comparison to minimal discharge of calendar month is evident. Floods evoked by short-term rain-falls may occur during a calendar month and in such case minimal discharge will be increased and will not reflect the natural process of runoff in dry period. When drought period in rivers is long and constant, Q_{month} and Q_{30} differ insignificantly, however during wet years period the differences are big. The largest differences between these characteristics are in Western Lithuanian rivers, where ratio Q_{month}/Q_{30} is in the interval of 1.16-1.29. In Middle and Southeastern Lithuanian rivers this ratio is 1.10-1.18 and 1.04-1.06, respectively.

The dry 30-day period in Lithuanian rivers runoff is observed during May-October, whereas in smaller rivers it is usually observed in June-August (in 80-83% cases), in the big rivers Nemunas and Neris - during July-September (78-80%) (Table1). According the longest time series of timing of 30-day dry period in Lithuanian rivers runoff we found that the essential shift occurred from June to August comparing the periods up to 1960 and from 1961. This is especially characteristic for Western Lithuanian rivers (Table1).

Table 1. Frequency of timing of the dry 30-day period in Lithuanian rivers runoff up to 1960 and from 1961

Months	05	06	07	08	09	10
to 1960						
Frequency, %	6.0	35.9	23.6	19.6	12.3	2.6
1961-2003						
Frequency, %	7.4	14.1	24.4	37.3	16.6	3.2

Chronological sequence of timing of dry 30-day period in the Nemunas river runoff is given in Fig. 1. In the period of 1893-1960 the dry period used to begin around July 20th, whereas since 1961 around August 10th.

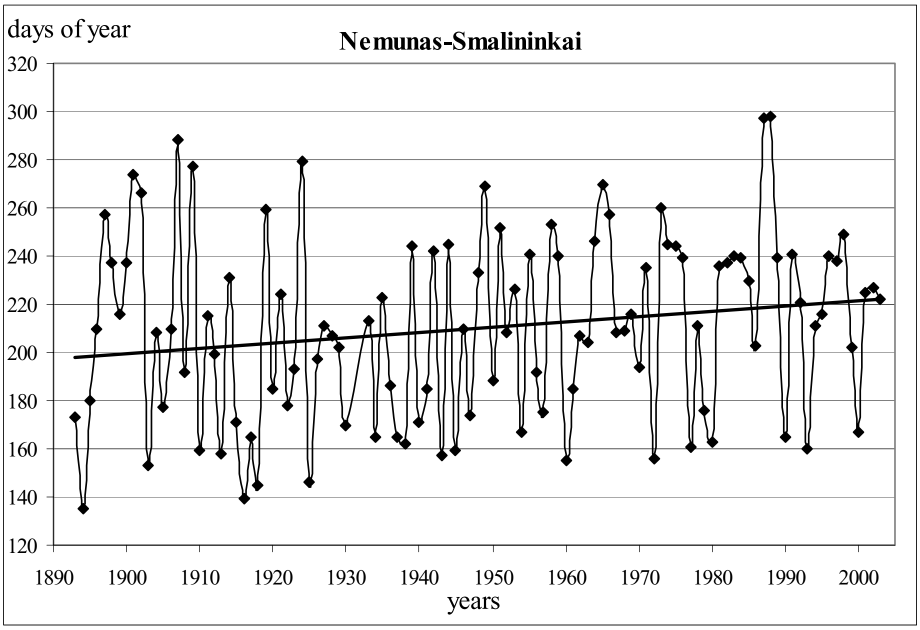

Figure 1. Chronological sequence of timing of dry 30-day period in the Nemunas river runoff

Cyclic variation of 30-day minimum discharges

Cyclic runoff variation is characteristic in Lithuanian rivers, i.e. there are similar duration periods of dry and wet years, during which average runoff values are significantly larger than average annual (modular coefficient of discharges K>1.0) or smaller (K>1.0) (Kriauciuniene, 2006). There is a close correlation connection (0.95-0.99) between annual runoff and minimal Q_{30} days runoff in Lithuanian rivers. Thus cyclic variation of Lithuanian rivers minimal runoff is determined as well. It is best to evaluate minimal runoff variation cycles in Lithuanian rivers according long time series of runoff observation in the Nemunas near Smalininkai (1812-2003). Runoff data of this hydrological station represent 72% of Lithuanian area. Average modular coefficients of cyclic fluctuations periods for precipitation (data of Vilnius meteorological station), annual and 30-day minimum discharges (data of the Nemunas river near Smalininkai) are presented in Table 2. In period of 1812 - 2003 seven full wateriness cycles are determinated, the average duration of which is 27 years, average duration of dry cyclic phase is 14 years, whereas of wet phase – 13 years.

Table 2. Dry and wet periods of annual precipitation and the Nemunas river runoff (annual discharge and 30-day minimum discharges)

Period	Number of years	Average of modular coefficient k_i in period		
		precipitation	Q_{annual}	Q_{30}
1812-1819	8	-	0,95	0,95
1820-1833	14	-	1,06	1,09
1834-1843	10	-	0,91	0,91
1844-1856	13	-	1,07	1,03
1856-1870	14	-	0,90	0,96
1871-1883	13	-	1,07	1,09
1884-1901	18	0,90	0,97	0,90
1902-1909	8	1,01	1,08	1,22
1910-1923	14	0,86	0,97	0,90
1924-1935	12	1,13	1,14	1,11
1936-1947	12	0,98	0,97	0,93
1948-1962	15	1,11	1,05	1,00
1963-1976	14	0,97	0,84	0,87
1977-1990	14	1,06	1,05	1,18
1991-2003	13	0,92	0,90	0,94

Cyclic fluctuations of minimal runoff determined according long time series of the Nemunas river runoff are characteristic for other Lithuanian rivers as well, in which runoff observations have been begun later on – in some since 1925-1926, in most – since 1945. Cycles of dry ($K<1.0$) and wet ($K>1.0$) phases differ in 1-2 years. In the dry period of 1963-1976 modular coefficient of Q_{30} is 0.89 in Southeastern Lithuanian rivers, whereas in Middle and Western Lithuania are 0.77 and 0.72, respectively. In wet period of 1977-1990 the modular coefficient K is 1.09 in Southeastern Lithuania, whereas in Middle and Western Lithuania even 1.47 and 1.35.

Comparison of standard normal of Q_{30} of Lithuanian rivers, determined for the period 1961-1990, is done with average of Q_{30} for 1991-2005. 30-day minimum discharges of the last period are smaller in the whole Lithuanian territory: Southeastern Lithuania - on average 4.5%, Central Lithuania - 19.6% and Western Lithuania - 16.3%, Nemunas and Neris 12.3%. The reason of decreasing of Q_{30} is dry phase runoff in 1991-2003.

Trends of 30-day minimum discharges

The longest sequence of the discharges of the dry 30-day periods is observed in the Nemunas river near Smalininkai. Figure 2 presents chronological sequence of Q_{30}. There is no trend in annual variation of minimal discharges.

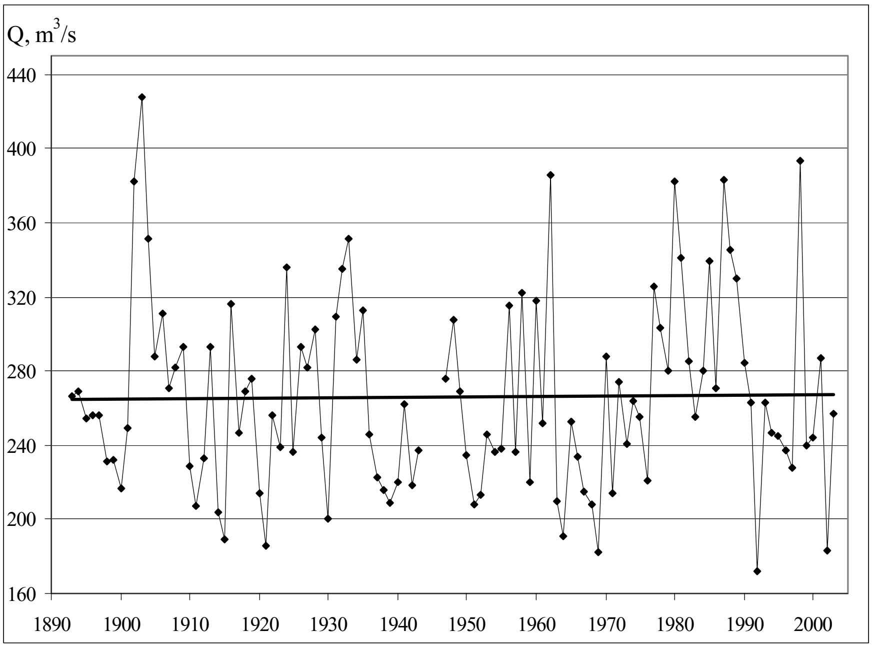

Figure 2. Variation of 30-day minimum discharges in the Nemunas river runoff

Analysis of the 30-day minimum discharges of Lithuanian rivers was carried out for data from 30 hydrological stations. Three time periods (1922 – 2003, 1941-2003, 1961-2003) of data were selected for analysis by Mann-Kendall test. During period of 1922-2003 it is possible to valuate trends of Q_{30} only according data of large Lithuanian rivers Nemunas and Neris (Figure 3). There are no significant trends of Q_{30} in this territory. In the period of 1941-2003 the minimal runoff of Nemunas and Neris also has no trends, whereas some stations in Middle Lithuania already have positive trends. Similar character of trends is for period of 1961 – 2003. Almost in all Lithuanian territory there are no significant trends in minimal runoff variation, except Western Lithuania, in which part of rivers will have positive trends. Such variations were determined by a very wet period of 1976-1990, the average module coefficients K in this territory were in the range 1.15-1.54.

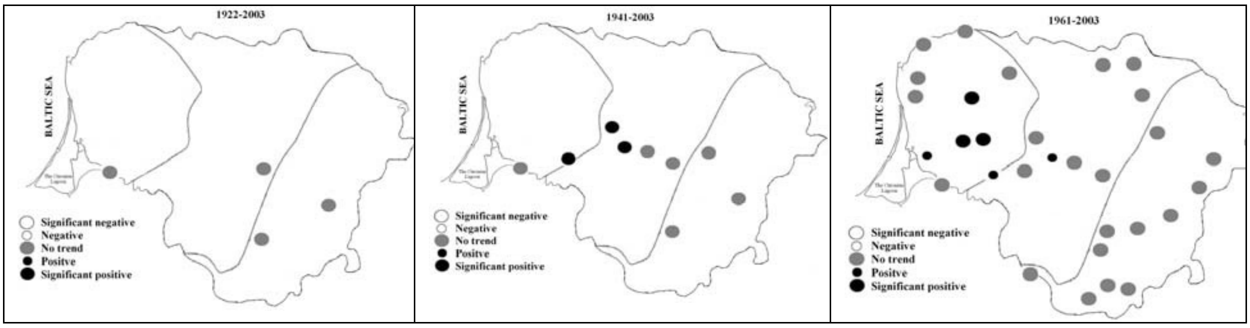

Figure 3. Trends of 30-day minimum discharges for the periods 1922-2003 (left), 1941-2003 (middle) and 1961-2003 (right)

CONCLUSIONS

1. In Lithuanian rivers the droughts (minimal 30-day discharges) are observed during June-August. Since 1961 they have been observed more rarely during June and more frequently during August.
2. The cyclic variations in the time series of the 30-day minimum discharge are typical for all Lithuanian rivers. The average period of the cycles is 27 years, including the average wet period of 13 years and the dry period of 14 years. The character of cyclic variations of annual discharge and 30-day minimum discharge is similar.
3. The minimal runoff analysis by Mann-Kendal test revealed that there are no trends in annual variation of the 30-day minimum discharge, only minimal runoff of some rivers in Western Lithuania

have positive trends in the period of 1961 – 2003. Such nature of variation was determined by very wet period of 1977-1991 in this territory.

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Ice cover of Lake Baikal as an indicator of recent warming

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Key words: Lake Baikal, Ice-Cover period, Maximal Ice Thickness.

ABSTRACT

The rise of air temperature on the Earth in the 20th century, especially for the past three decades, as well as other changes of the environment, caused the reduction of the ice area and decrease of the ice period in the Arctic region. Similar phenomena (rise of air temperature, decrease of ice cover period and its thickness, etc.) are observed on Lake Baikal. According to the Hydrometeorological Survey (HMS) data, the assessment of the dynamics of ice cover time over the period of instrumental observations on Lake Baikal (1950-2006) is of great interest due to Global Change - warming on the Earth. The analysis of changes in ice cover period beginning from 1870 and maximal ice thickness from 1950 to 2006 shows their systematic decrease the values of which vary depending on the regions of the lake. Linear trends, their slopes and moving average 30-year (climatic trends) have been estimated from annual characteristics of the ice cover. Slopes of linear trends of the ice cover significantly increase (more than two times) with the change of the geographical latitude, i.e. the ice cover period in Northern Baikal decreases faster than in Southern Baikal. The decrease of maximal ice thickness is even around the whole lake except at the hydrometeorological station in Babushkin in Southern Baikal where the decrease of maximal ice thickness occurs two times faster than in other regions of the lake. This work deals with the estimates of probable values of ice cover period and maximal ice thickness of Lake Baikal by 2050 retaining recent tendencies of climatic processes. Changes of ice characteristics on Lake Baikal and in the Arctic are in good correlation.

INTRODUCTION

Lake Baikal is the deepest freshwater lake in the world. According to the latest data, its maximal depth is 1642 m, volume – 23615 km^3, surface area – 31720 km^2, mean depth 744 m, length on the line of maximal depth (thalweg) -672 km. It is located between 51.4° and 55.7° N, 103.4° and 110° E (Sherstyankin et al. 2006).

By its morphological characteristics Lake Baikal is divided into Northern, Central and Southern Baikal with clearly expressed basins with maximal and mean (in brackets) depths: 904 (576), 1642 (853) and 1461 (843) m, respectively (Sherstyankin et al. 2006).

Lake Baikal may be called a small ocean as it has similar characteristics of geological, hydrological and climatological processes. For example, Lake Baikal is expanding like the Atlantic Ocean. Lake Baikal age which geologists estimate as 65 mln years (Logachev 2003) can be undoubtedly compared with the age of an ocean within time scales. Lake Baikal is situated in the heart of Eurasia in Eastern Siberia. From the viewpoint of climate, the North Atlantic significantly affects Lake Baikal, as well as the Arctic Ocean. In 1935, V.V. Shuleikin (1953) discovered the existence of temperature auto-oscillation regime between the North Atlantic and the polar basin (the Arctic Ocean). The dependence of weather and climate of the Lake Baikal area on the North Atlantic and the Arctic basin was also shown. Striking results on disastrous paleophenomena were obtained – Heinhrich events on Lake Baikal: their forecast (Kuimova, Sherstyankin 1999) and confirmation during deep drillings (Prokopenko et al. 2001; etc.). It appeared that control (keys) of weather and climate on Lake Baikal lie in the North Atlantic (Kuimova, Sherstyankin 1999). Lake Baikal and the Arctic Ocean have another common feature – ice cover. However, there are also principal differences. The ice cover on Lake Baikal

appeared about 3 mln years ago (Kuimova, Sherstyankin 1998; Sherstyankin, Kuimova 2006) and never lasted during the whole year (Shimaraev, Granin, Kuimova 1995; Kuimova, Sherstynkin 1998; Sherstyankin, Kuimova 1998). The ice cover in the Arctic Ocean (most likely as a perennial phenomenon) appeared about 900 thousand years ago (Khusid et al. 1993).
It should be noted that climate is considered to be weathers (e.g. IPPC) averaged for a classical period of 30 years. It allows to analyze both annual amplitudes and climatic changes (moving average at 30 years).

This study focused at analyzing the changes of ice regime characteristics on Lake Baikal taking into account climate warming during the 20th century on the Planet and vivid warming since 1970, and at evaluating their possible changes by 2050.

MATERIALS AND METHODS

This work presents the results of observations carried out at hydrometeorological stations (HMS) located on the Lake Baikal shores (Fig. 1) beginning from 1950 to 1988 and published in Handbook on Climate USSR (example 1970 etc). Since 1989 we have got data from Irkutsk Hydrometeological Center within the framework of joint research. The only long series of data on duration of ice cover beginning from 1869 is related to site Listvyanka, Southern Baikal (www.lin.irk.ru).

Fig. 1. Location of Lake Baikal on the Eurasian Continent. Hydrometeorological stations and sites on Lake Baikal.

There is a long series of data on air temperature obtained at HMS Babushkin (since 1896). The data and methodic were published in Climatological Reference Book of the USSR and Meteorological Monthly Magazines by Publishing House of Hydrometeorological Survey – Hydrometeoizdat, for example: Handbook on Climate SSSR, Issue 22, 1970; Instruction …, Issue 7, Leningrad, 1948.
The data on climate changes of the Earth and the Arctic were borrowed for comparison from "The Intergovernmental Panel on Climate Change (IPCC)", Johannessen et al. (2004), Vinikov et al. (1999) and other.

RESULTS

Duration of ice cover period on Lake Baikal

The duration of ice cover period and maximal ice thickness are major characteristics of the ice regime which are under discussion in this paper. Every year the ice cover on Lake Baikal is formed in December-January, and its duration varies in different years – 72-142 days in the south of the lake and 104–166 days in the north. The results of the analysis of the longest series of observations o the lake ice cover in Listvyanka settlement are very interesting. These observations were started in 1869 and are still being continued (www.lin.irk.ru) (Fig. 2). The maximal period of ice cover (157 days) was recorded in 1879, and the minimal one -72 days in 1959. In 1982-1984 the ice cover period was 95 days, but interannual variations were not recorded for three years. Maximal variations of 43, 44 and 42 days were observed in 1900, 1932 and 1992, respectively.

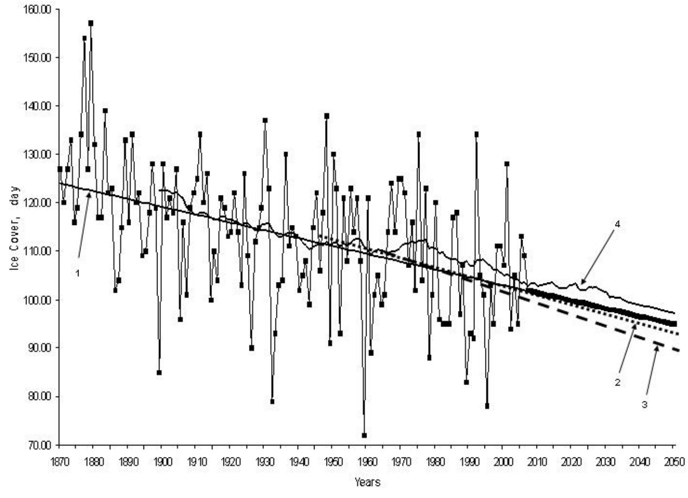

Fig. 2. Duration of ice cover period on Lake Baikal, Listvyanka settlement, in 1870-2006 – black squares; linear trends in 1870-2006 – a thin line 1, in 2006-2050 – a bold line; 1950-2050 – a dotted line 2; 1970-2050 – a bold dashed line 3; moving average 30-year (climatic trend) in 1870-2005 with an extrapolation till 2050 – a bold broken line 4.

Interestingly, minimal periods of ice cover are recorded approximately within 30 year intervals (1899 – 85 days, 1932 – 79 days, 1959 – 72 days, and 1995 – 78 days). They are close to the years with low water levels and their intervals (Afanasyev 1967). The minimal periods of ice cover coincide with the periods of low water levels, rise of air temperature and considerable heating of Baikal surface waters. The linear trend (line 1) for 1870-2006 (Fig. 2) is not of high statistic reliability (about 0.5) due to considerable interannual changes. However, there is a stable tendency in decrease of ice cover period from 124 days at the beginning to 103 days at the end of the period. The climatic trend, moving average 30-year, (curve 4) coincides with cooling in 1875-1880, 1950-1958, and 1966-1973, and then the curve is similar to the linear trend (line 1), Fig. 2.

The linear trend of 1950-2006 (line 2) has a tendency to the insignificant increase in warming in comparison with that in 1870-2006. According to the analysis of average annual air temperatures in Irkutsk and HMS Babushkin, the rate of warming for the past 30 years became two times higher reaching 2 and 1°C per 100 years (Kuimova, Sherstyankin 1998). Approximately the same rates of shortening of ice cover period were observed in Listvyanka in 1970-2005 (line 3) compared to 1950-2005 (line 2) – 9 and 13 days per 50 years.

Duration of ice cover period on the north-western (NW) and south-eastern (SE) coasts of Southern Baikal, for Central and Northern Baikal is shown in Fig. 3. All the linear trends of ice cover period in 1950-2005 show shortening of ice cover period for Southern (NW and SE), Central and Northern Baikal by 22, 32, 32, and 28 days, respectively. Thus, there is a vivid tendency to warming.

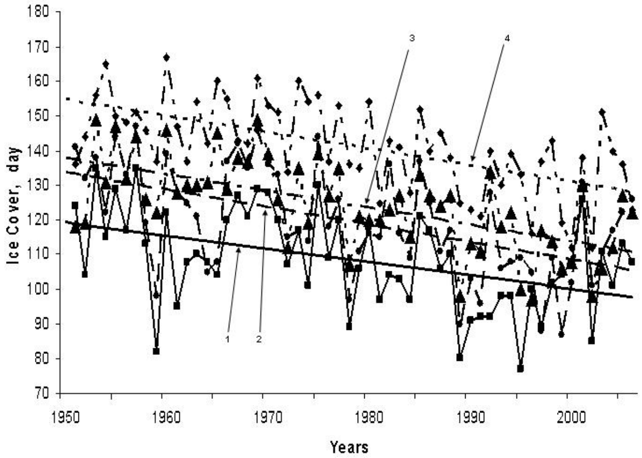

Fig. 3. Duration of ice cover period on Lake Baikal in 1950-2006. Southern Baikal NW – small square, linear trend 1; Southern Baikal SE – filled circles, linear trend 2; Central Baikal – triangle, linear trend 3 and Northern Baikal – rhombus, linear trend – 4.

Maximal ice thickness

This characteristic of ice cover is very sensitive to climate changes in the studied area. According to the data on maximal ice thickness on Lake Baikal, the linear trend in 1950-2005 shows the decrease from 92 cm at the beginning to 77 cm at the end of the studied period (Fig. 4a). The minimal ice thickness was recorded in 1959, 1995, 2002 and 2004 – 61, 60, 51, and 60 cm, respectively. Data dispersion in maximal ice thickness relative to the linear trend in 1950-2005 is very wide. However, this trend is close to the trend for a long-term period as for the periods of ice cover.

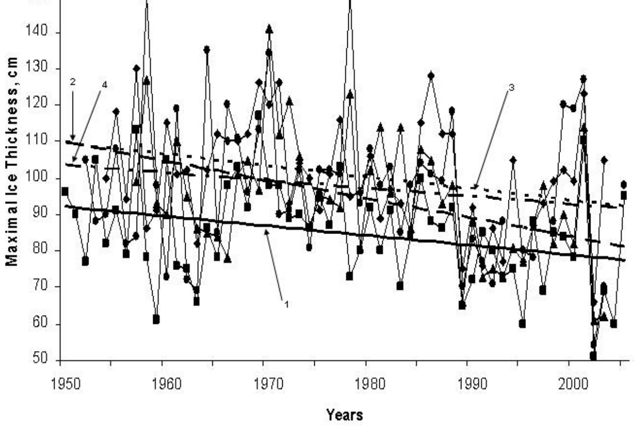

Fig. 4. Maximal Ice thickness on Lake Baikal in different regions in 1950 – 2005.
Listvyanka – small square, linear trend 1; Babushkin – triangle, linear trend 2;
B. Ushkanii Isl. – rhombus, linear trend 3 and Nizhne-Angarsk – filled circles, linear trend 4.

The slope of the linear trend for this area in 1970-2005 is from 94 cm to 73 cm, i.e. the rate of warming is almost two times higher than that of 1950-2005.

DISCUSSION

The dynamics of ice cover period and period of open water during instrumental observations (1951-2005) recorded at HMS of Lake Baikal is of great interest due to universal climate warming on the Planet. For instance, observations in the Arctic show considerable changes in climate on the Earth. For the past years, anomalies of surface air temperatures ΔTair (SAT) in the arctic latitudes (60-90°) grow faster than in the 45-55° latitudes (Bengtsson et al. 2004), and the growth of ΔTair is faster than in lower latitudes. The minimal growth of ΔTair is observed at 60° S (Johannessen et al. 2004, http://www-pcmdi.llnl.gov/cmip), i.e. in the Southern Ocean where the stabilizing effect of the ocean on climate is the highest.

It is known from numerous official sources that for the last century the rise of mean annual air temperature on the Earth was 0.6^{o}C, for the Russian territory - 2.6^{o}C/100 yr in1951-1998, while on Lake Baikal (HMS Babushkin) - 1.1^{o}C/100 yr. Taking into account the latest data (1896-2005), according to HMS Babushkin data the temperature rise makes up 1.4^{o}C. Climatic characteristics in different parts of Lake Baikal differ significantly. Mean annual air temperatures Tair for different basins of the lake make up 0.3°C for Southern Baikal, -2°C for Central and 3.9°C for Northern Baikal. In Peschanaya Bay at the interface between Southern and Central Baikal, Tair reaches even +0.9°C, i.e. it is the only place on Lake Baikal where the mean annual temperature is higher than 0°C.

The survey in the Arctic Ocean carried out from the ice surface and under the ice (echosounding from submarines) demonstrated significant decrease of thickness of the Arctic ice in different regions of the Arctic Ocean. The ratio of ice thickness in 1993-1997 to that in 1958-1976 makes up on average 0.42 (the decrease was more than two times) (Rothrock et al. 1999). The ratio of maximal ice thickness in 2005 to that in 1950 in different areas of the lake changed from 0.75 to 0.84 and was on average 0.81 (Fig. 5). It is interesting to note that the most significant changes in ice thickness took place in Northern Baikal, i.e. the intensification of warming with the change of the latitude is also observed on Lake Baikal (compared to the zonal mean ΔTair according to Johannessen et al. 2004; http:///www-pcmdi.llnl.gov/cmip).

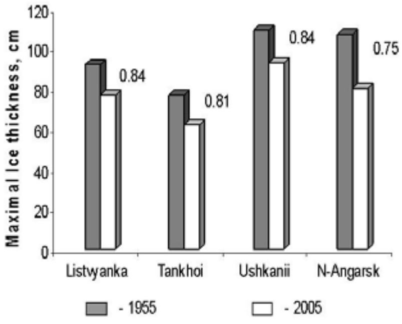

Fig. 5. Maximal Ice thickness in Listvyanka, Tankhoi, B. Ushkanii Isl. and Nizhne-Angarsk on Lake Baikal in 1955 and 2005.

On estimates of ice period cover by 2050

Such estimates can be obtained with approximation of linear and climatic trends for different periods assuming that reasons causing warming and changes in trend character will remain the same. Under such conditions the duration of ice cover period by 2050 will have been equal according to linear trends: observations from 1870 (trend 1) – 95 days, from 1950 (trend 2) – 94 days, from 1970 (trend 3) – 90 days and for a climatic trend (4) from 1870 – 97 days. The estimates obtained are of a preliminary character.

On estimates of ice thickness by 2050

The analysis of linear trends (Fig. 4) shows that the maximal ice thickness in different regions of Lake Baikal varies significantly. Thus, rate reduction maximal ice thickness is near Babushkin twice as many.

The recent analysis of annual sea-ice extent (area within the ice-ocean margin) derived from new "Zakharov" sea-ice data set, Northern Hemisphere sea-ice extent from the widely used "Walsh" data set and zonal (70-90^{o}N) mean annual SAT since 1900 allows to estimate mathematical expectations of ice extent in 2050 (Vinnikov et al. 1999). The ice extent is expected to decrease from 12 mln km^2 in 1990 to 10.1 mln km^2 in 2050. The estimates on ice cover period to 2050 are based on the similarity of behaviour of characteristics of the ice regime in Lake Baikal and sea-ice extent of the Arctic Ocean at present and on supposition that these relations and tendencies will remain the same for the nearest 50 years.

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Mentally preparing for climate adaptation: The role of cognition in enhancing adaptive capacity of water management in Kiribati

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Keywords: Climate change, water resources, adaptation, protection motivation theory, small islands

ABSTRACT

In many LDCs and SIDs[2], such as in Kiribati, formal national adaptation programmes are currently being operationlised or in the pipeline, where a key focus is on motivating householders to anticipatorily adapt via pilot community projects. Previous work on understanding adaptive capacity has focused on its objective elements but we argue that the water sector must pay equal attention to how communities cognitively perceive the process of adaptation if planned interventions are to be effective. In this paper we present and analyse findings from a recent case study on climate adaptation within water resource management in Kiribati, adopting cognitive heuristics to gain insights into crucial antecedent elements required to motivate householders to increase their adaptation intention. Three main lessons can be drawn. First, the ease of observing secondary impacts of climate change e.g., sea level rise (SLR) can lead to an increased understanding of climate change impacts on water resources devoid of fully understanding the physical 'climate change' process. Second, the perceived *severity* of the phenomenon 'climate change' differs from 'climate change impacts on water resources' due to distinct cognitive constructs, initiating feelings of uncontrollability. Third, self-efficacy beliefs conducive for anticipatory behaviour towards water resources are conditioned by past experience with water stress rather than an understanding of climate impacts where over-confident beliefs stand to impede adaptation. Based on these results, self-efficacy beliefs related managing water stress play a key role in driving adaptation intention formation and greater attention needs to be placed on understanding the underling drivers shaping such beliefs.

INTRODUCTION

Climate change is an existing reality for many individuals in the developing world and Indigenous communities living on the margins, offering a minimal time frame to move anticipatory adaptation[3] to the core of their decision making process. The task is not straightforward as demonstrated by communities struggling to comprehend the logic of mitigation (Sterman and Booth Sweeney, 2007). Thus, the motivation for anticipatory adaptation, is initially an intellectual process, "where individuals need to think about the concept and be able to relate to and understand the term, only then can behavioural change follow" (Hughes, 2006). However, scholarship on understanding the process of enhancing adaptive capacity has traditionally suppressed its antecedent subjective[i] dimensions (i.e., human perceptions of risk and perceived adaptive capacity), that in combination with objective elements drives the adoption of anticipatory adaptation (Grothmann and Patt, 2005, Weber, 1997). The few empirical studies that exist bring to the fore insights from local perceptions of climate change, enhancing our understanding of cognitive elements attached to adaptive response (Sundblad et al., 2007, Grothmann and Patt, 2005, Vedwan and Rhoades, 2001).

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[2] Least Developed Countries (LDCs) and Small Island Developing States (SIDs). Kiribati has two national adaptation projects.

[3] Anticipatory adaptation is the "adjustment [undertaken in advance] by a system to moderate the impacts of climate change, to take advantages of new opportunities or to cope with the consequences" (Adger et al., 2003, p.15). Adaptive capacity is defined by "the set of resources (natural, financial, institutional or human, and might include access to ecosystems, information, expertise, and social networks) available for adaptation, as well as the ability or capacity of that system to use these resources effectively in the pursuit of adaptation," (Brooks and Adger, 2004, p.168).

THEORETICAL CONTEXT

The research adopts key elements from the Model of Private Proactive Adaptation to Climate Change (MPACC) (Figure 1) proposed by (Grothmann and Patt, 2005), based on the original Protection Motivation Theory developed by (Rogers, 1983) to understand cognitive processes mediating adaptive/maladaptive behaviour. A person's intention to protect one self via adaptation is based upon the outcomes of two cognitive appraisal processes: "*risk appraisal* – the perceived probability of being exposed to the risk[4] (vulnerability) and its perceived severity (consequences of threat); and *adaptation appraisal* - ability to avert being harmed by the threat, along with the costs of taking such action and results in an awareness of perceived adaptive capacity," (Grothmann and Patt, 2005, p.5). Detected stimuli from the objective world are "stored and organised in the mind so that it fits in with existing knowledge [*based on previous experiences*] and values of the person" (Golledge and Stimson, 1987, p.38). Piaget's theory refers to these cognitive structures by which individuals process and identify incoming stimuli as 'schema' which are dynamic and constantly updated (never replaced) via assimilation[5] and accommodation as a result of the developmental process (Wadsworth, 1984).

The adaptation appraisal process consists of three key components: "*perceived adaptation efficacy*, i.e., the belief in the effectiveness of adaptive actions in protecting oneself (exclusive of maladaptive actions); *perceived self-efficacy*, i.e., belief in one's ability to successfully perform the actions; and *perceived adaptation costs* refers to the assumed costs (inclusive of monetary, personal, time, effort) of undertaking the actions," (Grothmann and Patt, 2005, p.5). The outcome of this process is a decision or intention (*adaptation intention)* to undertake the adaptive action. "However, good intentions do not necessarily guarantee corresponding actions…. as correlations between goals and behaviour vary greatly," (Schwarzer and Fuchs, 1995, p.279) due to deficiencies in our objective adaptive capacity (e.g. access to assets, networks, knowledge) (Grothmann and Patt, 2005, Webb and Sheeran, 2006). Past experience with specific types of harmful events (particularly its severity) can enhance self-efficacy beliefs and motivate people to take precautionary actions in anticipation of similar events that may unfold in the future (Grothmann and Patt, 2005, Tompkins and Hurlston, 2003).

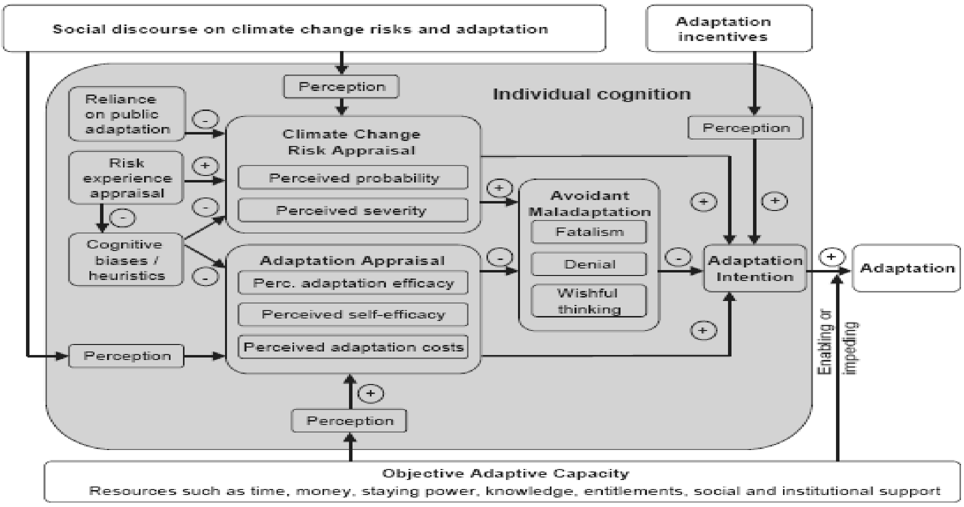

Figure 1. Model of private proactive adaptation to climate change (Grothmann and Patt, 2005)

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[4] Jaega, Renn et al.(2001, p.17) defines risk as "a situation or event in which something of human value (including humans themselves) has been put at stake and where the outcome is uncertain."

[5] Assimilation involves integration of new perceptual matter into existing schemata whilst in accommodation a new schema is developed for the stimulus or an existing schema modified (Wadsworth, 1984, p.15))

METHODS

The Republic of Kiribati comprises of 33 low islands (average width 450m, height above sea level 3m), straddling the central Pacific with a population of 93,000, covering a landmass of only 730 sq km. The country is extremely isolated and approximately one-third of the population lives in the capital South Tarawa, placing a great strain on the limited groundwater resources which is found in the form of freshwater lenses[6] (freshwater floating on denser saltwater). Climate change is likely to affect the water resources in Kiribati through variations in rainfall (current average is 2,745 millimeters), evapo-transpiration, increases in sea level and extreme events (World Bank, 2000).

The study aimed to disaggregate the 'human' sphere and tease out its subjective layer as a means to understanding commonalities between individual risk perceptions regarding climate change impacts on water resources and its implications for private anticipatory behaviour. A householder level semi-structured survey (total, 132 interviews) was conducted on three islands (covering five villages[7]) of the Gilbert Island cluster (South Tarawa, North Tabituea and Butaritari), each possessing distinct cultural and climatologically contexts. Butaritari receives higher than average rainfall, South Tarawa average rainfall and North Tabituea is one of the driest islands. Respondents on all islands had access to a traditional well, whilst in South Tarawa this was complemented by a reticulated water system operated by the Public Utilities Board (PUB).

RESULTS

> "We don't need to hear about climate change on the radio or read about it in the newspapers as most of us live near the sea so we can notice the changes," (Betio respondent, 56-65 age group).

The qualitative data was analysed to elicit trends within and across islands as related to the objectives of the paper. Over half the respondents across all three islands had observed significant changes to both their climatic patterns and water resources, except in Butaritari where high rainfall tended to mask changes to water resources. Common changes experienced included saltwater intrusion and lower/higher water levels in wells. Most respondents (90%) were able to provide causal explanations for changes to water resources but a majority (75%) had *no idea* of the causal drivers behind changes to local climatic patterns. Respondents predominantly attributed changes in water resources to natural drivers and indirect drivers of climate change i.e., SLR and increased temperatures whilst changes to climate patterns were attributed to unsustainable local practices such as vegetation clearance, land reclamation, construction of seawalls and causeways rather than anthropogenic climate change.

Significant differences existed between respondents' understanding of the following two processes: climate change (i.e., its causes, consequences and impacts) and the impacts of climate change on water resources. Over 80% of respondents understood the potential impacts of climate on their water resources with most identifying saltwater intrusion from SLR and less water availability from increased drought events as major threats. Despite 60% (mean) of respondents across the islands being aware (i.e., alert) of climate change, particularly its consequences (i.e SLR) for Kiribati, their understanding of climate science was unmatched. Understanding differed amongst Betio (55%) and rural (i.e., outer islands of Taibtuea North and Butaritari) respondents (30%), most likely attributed to the higher levels of education amongst Betio respondents and their accessibility to a variety of media sources, besides radio. Nevertheless, inconsistencies remained within their understanding, where respondents were able to identify emission pathways of GHGs but unable to provide an explanation as to how GHGs produce atmospheric warming.

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[6] No surface water exists on the islands with rainwater harvesting practiced to a limited extent.

[7] Villages included: Betio village- South Tarawa; Kabuna and Tekabwibwi- Tabituea North; and Vaticano and Tanimaiaki- Butaritari. Betio village is an urban setting whilst all others are rural (subsistence lifestyle).

In attempting to understand respondents' perceived vulnerability and severity of climate change, respondents were questioned whether they felt worried or not about climate change and their reasons for [un]concern. Across the three islands, most respondents (47%) remained worried about climate change impacts, particularly SLR but with limited understanding of climate change, 33% of rural respondents were unsure whether they should be concerned. On average 20% of respondents from all islands remained unconcerned, mainly due to their faith in God. Respondents perceived the severity of climate change as the main cause for concern, particularly SLR having the potential to cause irreversible damage by 'drowning the islands' and displacing the I-Kiribati population. Attached to perceptions of worry were feelings of uncontrollability over the extreme flooding expected to be caused by SLR. Most respondents felt vulnerable to SLR due to the narrowness and low-lying nature of the islands.

Respondents perceived adaptive capacity was ascertained by questioning the types of adaptation actions they could undertake in preparation for expected impacts on water resources and their perceived barriers to action. These questions were complemented by inquiry into respondents past behaviour related to water management during the 1998 drought event which impacted all three islands. Marked differences existed in adaptation intention formation of Betio versus rural respondents where on average 80% of rural respondents had not previously thought about adaptation compared to 10% of Betio respondents. Results from the drought experience indicated most rural respondents (mean 60%) continued existing water use practices, not feeling the drought whilst only 30% of Betio respondents shared a similar experience. The drought forced most Betio respondents who were relying on a single source of water to switch to utilising new sources such as the PUB tanker service, borrowing rainwater or drinking well water. On a positive note, only eight respondents (11%) from Betio perceived nothing could personally be done to adapt besides relying on the PUB. The main adaptation actions identified included the purchase of rainwater tanks and construction of additional standby wells. Although respondents' believed in the effectiveness of these adaptation actions, they identified adaptation costs as the main barrier to implementation of adaptation intention.

DISCUSSION AND CONCLUSIONS

Respondents found it simpler to conceptualise and comprehend the process 'climate change related to water resources' rather than the science of 'climate change' due to the ease of observing underlying causal drivers and the existence of schemata connected to water stress. Although respondents may have an understanding of increased GHGs causing SLR, their reluctance to link observed climatic variations to climate change is due to difficulties in physically observing GHGs. In contrast, the ease of observing secondary drivers of climate change (e.g., SLR) and subsequent manifestations on water resources, led respondents to clearly grasp the links between climate change and water resources. Experience with past climate related water stress had enabled respondents to fine-tune their schematic representation of 'climate change related to water resources', whilst in the absence of sound schema pertaining to climate science, respondents were inclined to assimilate and attribute the observed climatic variations to existing local pressures for which schemas had been developed. By cognitively restructuring the situation where one is aware of the likely course of actions and outcomes, individuals' can reassert a sense of 'control' over uncertainty (Mandler, 1990).

> "I have heard about global warming and its effects such as SLR. They said in the paper that global warming is caused by a blanket covering the atmosphere but because I can't see the blanket, it makes it hard for me to fully understand and believe in global warming. I just experience its effects," (Betio respondent, age group 46-55).

The perceived *severity* of 'climate change' and 'climate change related to water resources' differed due to distinct cognitive construct systems underlying the two processes. The limited formal awareness raising and misguided media reporting had contributed to the confusion surrounding the public's perceptions regarding climate change. A strong schematic disconnect existed between respondents observed climatic changes and their expectations of how climate change will unfold. Respondents perceived climate change as a threat but their existing schema reflected its severity as a long-term, uncontrollable extreme event i.e., SLR submerging the islands rather than short-term impacts, e.g., salinisation of lenses. Moreover, these perceptions stood to concurrently decapitate respondents' self-efficacy beliefs in adapting. Adopting avoidant maladaptive behaviour such as faith in God, enabled respondents to suppress feelings of hopelessness and fears of the threat (Rippetoe and Rogers, 1987). In contrast, the unfolding of climate change impacts on water resources was perceived to be controllable and less threatening since impacts were envisioned to manifest as extensions of past conditions of water stress, leaving room for complacency in adaptation. Thus, water professionals must be cautious in the types of climate change scenarios adopted for awareness raising programmes and determine a middle path to pitch the threat to water resources.

Self-efficacy beliefs conducive for anticipatory behaviour towards water resources are conditioned by past experience with water stress rather than an understanding of expected climate change impacts where over-confident beliefs stand to impede adaptation. Variations in adaptation intention formation existed between Betio and rural respondents due to respondents experience with past water stress, particularly the 1998 drought. According to Webb and Sheeran (2006), when behaviour is performed infrequently in unstable conditions (e.g., 1998 drought), intention is a better predictor of future behaviour whilst frequently practiced behaviour in a stable context (e.g., recurrent dry weather) becomes habitual with individuals less likely to form an intention to adopt new behaviour. The drought coping strategies employed by Betio respondents were new (i.e., non-habitual) whilst Tabituea North respondents had successfully adopted similar strategies during previous dry periods, becoming permanently embedded within their water management schemas. Thus, adaptation intentions had been formed amongst Betio respondents to re-establish debilitating self-efficacy believes and reassert a sense of emotional control over future water stress.

The subsistence lifestyle on the outer islands had cultivated a sense of over-confidence amongst respondents, creating strong beliefs in efficacy pertaining to water management and thus acting as a barrier to intention formation. Unlike Betio respondents who were dependent on the PUB to solve their water dilemmas, outer islanders' had a mentality where one had to fend for themselves, particularly given most respondents utilise private wells. Their existing coping strategies had previously sufficed, devoid of major alterations, providing respondents' the confidence in their future utility whilst precluding the need for forming adaptation intentions. An additional underlying determinant was the limited understanding of the types of actions one could undertake to protect themselves, a factor absent from previous climate awareness raising initiatives in Kiribati. Grothmann and Patt (2005) assert that education programmes must encompass information on both the risks of climate impacts and effective, low-cost adaptation options if we are to prevent maladaptive responses (e.g. risk denial). However, education on adaptation strategies must also be matched by supply-sided water management initiatives that aim to diversify choice situations (Vlek and Steg, 2007). Adaptation programmes can benefit from targeting interventions to match the stages of existing behaviour where respondents at a latter stage (adaptation intention formed) may be less unreachable and demonstrate beneficial results which stand to motivate those at earlier stages (no intention to change behaviour) (Weinreich, 1999).

The research demonstrated that the relationships between perceived risk experience and adaptive capacity are quite complex, having implications for adaptation interventions. Even in the presence of institutional support it cannot be presumed that a high objective adaptive capacity of private individuals will automatically facilitate adaptation actions, unless cognitive barriers are simultaneously addressed. The results established that self-efficacy beliefs play a key role in adaptation intention formation, where a perceived threat to self-efficacy beliefs must be initially established prior to respondents seeking protective actions. Thus, an understanding of the underlying factors shaping such beliefs is necessary if barriers to water management are to be overcome. Although the research was restricted to personal self-efficacy beliefs, future work can be enhanced by determining the extent to which social networks may shape personal as well as social efficacy beliefs, and their implications for perceived adaptive capacity.

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Increasing threshold censoring for the peaks-over-threshold analysis of probabilities of extreme events: application to regional climate model outputs

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Keywords: regional climate models, climate change scenarios, extreme events, peaks-over-threshold analysis, heavy precipitation, central Europe

ABSTRACT

A peaks-over-threshold analysis with increasing threshold censoring is applied to estimate multi-year return levels of daily rainfall amounts in a large ensemble of control and scenario outputs of 10 regional climate models (RCM) over central Europe. Specific attention is devoted to the selection of threshold values used to delineate extremes and the estimation of confidence intervals. We focus on uncertainties in scenarios of changes for the late 21st century related to the inter-model and within-ensemble variability and the use of the SRES-A2 and SRES-B2 greenhouse gas emission scenarios. The results show that heavy precipitation events are likely to increase in severity in DJF and (with less agreement among models) also in JJA; however, the inter-model and intra-model variability (and related uncertainties) in the pattern and magnitude of the change is large. In most scenario runs, mean seasonal totals in JJA are projected to decline; a combination of enhanced heavy precipitation amounts and reduced water infiltration capabilities of a dry soil may severely increase peak river discharges and flood-related risks in the area.

INTRODUCTION

Coupled atmosphere and ocean general circulation models (GCMs) are the most frequently used tool in global climate modelling (IPCC, 2007). However, since the coarse grid scale of GCMs poses severe limitations with respect to the simulation of mesoscale processes and the representation of orography and land-sea distribution, subcontinental patterns are usually examined by means of nested regional climate model (RCM) experiments. RCMs enable a construction of GCM-consistent climate change scenarios with more regional detail and better representation of processes that lead to heavy precipitation (e.g. Frei et al., 2006). They have undergone a rapid development in recent years and have been increasingly used to analyze climate variations at scales that are not resolved by global models. Heavy precipitation events are frequently examined in their outputs as they are related to floods with enormous impacts on society. The topic is up-to-date in central Europe also because the region has recently been severely affected by record-breaking rainfall episodes that resulted in the massive summer floods of July 1997 in the Odra river basin (northeastern part of the examined area) and August 2002 in the Elbe basin (western part).

Most climate models are in a basic agreement concerning general increases in the frequency and intensity of heavy precipitation events under elevated GHG concentrations, mainly over land areas of middle and high latitudes. Despite the relative agreement concerning changes in extremes, significant differences have been reported with regard to their magnitudes and seasonal manifestation in central Europe, a region where Atlantic, Mediterranean and continental influences meet and where complex orography is associated to precipitation patterns that cannot be captured by low-resolution global models. That is why we focus on this area in detail and examine uncertainties in scenarios of future changes in heavy rainfall events related to the inter-model and intra-model (within-ensemble) variability and two different GHG emission scenarios, based on simulations of 10 current RCMs.

DATA

Basic characteristics of the 10 RCMs under study (altogether 24 examined scenario runs and 16 control runs from the PRUDENCE project) are given in Christensen and Christensen (2007). The RCM outputs have a horizontal resolution of about 50 km; the only exceptions are the high-resolution runs of the HIRHAM model with a 25 km grid. A driving GCM for all RCM simulations (control ones as well as scenarios) is the Hadley Centre HadAM3 GCM; the RCAO RCM is driven also by the ECHAM4 GCM. The ARPEGE model, which is a global model with a variable horizontal resolution, may be treated as a regional model over Europe interactively nested in a global model. The RCMs are run under SRES-A2 and SRES-B2 emission scenarios except for CLM, RACMO, CHRM and REMO for which only SRES-A2 runs are available. The A2 (B2) emission scenario leads to a more rapid (slower) increase in concentrations of GHG in the atmosphere compared to the A1B scenario referred to in IPCC (2007) as a baseline, thus representing another range of uncertainty in possible future changes. Late 21st century scenarios relate to the period 2071-2100.

Six out of the 10 RCMs were validated over Europe in Frei et al. (2006) who found a relatively good performance in simulating 5-yr to 50-yr return values of precipitation amounts in the present climate, the model biases for extremes being comparable to or smaller than those for mean precipitation and wet day intensity.

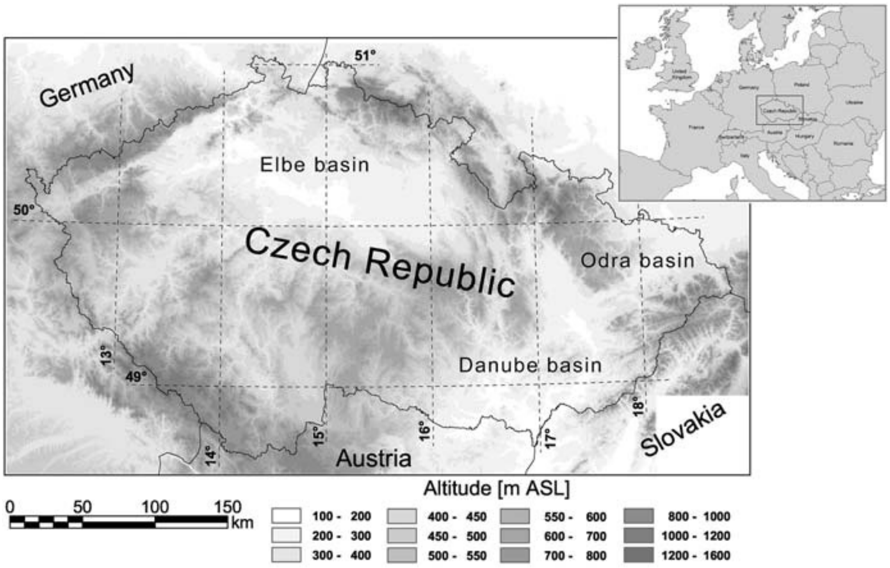

Figure 1. Area under study.

METHODS

Probabilities of heavy 1-day precipitation amounts in individual gridboxes are examined using a ‘peaks-over-threshold’ (POT) methodology. In this approach, all observations exceeding a sufficiently high threshold, respecting a given minimum distance between selected events so that their independence is preserved, are taken into account; only maxima of clusters of exceedances are considered. The method results in the Poisson process model for event arrivals, and utilizes the Generalized Pareto (GP) distribution for their magnitudes (Coles, 2001).

The independence of POT events must be achieved by a suitable combination of the threshold and minimum separation time (‘dead-time’) between exceedances. A too low truncation level makes the POT events too close in time, and introduces serial dependence of occurrence times and magnitudes; a too high threshold leads to a loss of information. We cover a wide preliminary range of possible thresholds $u = m + cs$ where $c = 1.0, 1.1, ..., 5.0$, and m and s denote the mean and standard deviation of the individual gridbox samples (only non-zero daily precipitation amounts are considered). The range of suitable thresholds for which the basic conditions of the POT analysis are met, i.e. the exceedances are independent and the thresholds are sufficiently high so that the asymptotic properties of the model are not violated, is determined using the test on the dispersion index (DI) and the mean residual life plot (Coles, 2001). The DI statistic is DI = $\frac{s_N^{2}}{m_N}$ (Cunnane, 1979) where s_N and m_N are estimated standard deviation and mean of the annual number of exceedances. For a Poisson process, DI is expected to be 1. Confidence levels for DI are calculated from a χ-square distribution with Y-1 degrees of freedom where Y denotes the number of years in the sample. The Poisson hypothesis is not rejected at the α significance level if the estimated DI is within the range ($\frac{\chi^2_{\alpha/2,Y-1}}{Y-1}, \frac{\chi^2_{1-(\alpha/2),Y-1}}{Y-1}$). Since a unique optimum threshold cannot be found in most cases, we adopt the procedure of increasing threshold censoring proposed by Begueria (2005). Parameters of the GP distribution are averaged over the range of threshold values (u_0, u_n) where the lower range u_0 is the lowest threshold for which the Poisson-GP model holds (according to the DI test statistics) while the upper limit u_n is the point where the process starts to be unstable on the mean excess plot or when the Poisson-GP model fails to pass the DI test. Estimation errors in this approach are approximately halved compared to a single threshold analysis (Begueria, 2005).

The evaluation of RCM-simulated changes in heavy rainfall events focuses on relative changes in 50-yr return levels of daily precipitation amounts; however, the basic findings hold true for a wide range of return periods. The significance of the future changes in T-yr return levels of daily precipitation is evaluated using a parametric bootstrap (e.g. Kharin and Zwiers, 2000) which consists in repeatedly generating samples of the same size from the fitted GP distribution, and a subsequent estimation of the parameters and quantiles of the 'new' GP distribution. From the bootstrapped distributions, obtained for the lowest appropriate threshold in the POT models (see Section 4.1), 80% and 90% confidence intervals of the quantiles are derived. If the 90% (80%) confidence intervals do not overlap, the change is statistically significant approximately at the 0.01 (0.07) level (e.g. Kharin and Zwiers, 2000, 2005). The analysis is carried out separately for summer (JJA) and winter (DJF).

RESULTS

Selection of thresholds for the POT analysis

Results of the test on the dispersion index and mean residual life plots are aggregated over all gridboxes in an individual model run. This is possible owing to the small extent of the area under study (Fig. 1), in which climatologically reasonable differences in shape parameters of the GP distribution of heavy daily precipitation amounts (leading to different slopes of the mean residual life plots) are not expected (cf. Kyselý and Picek, 2007).

Percentage of tests on DI that reject the independence of the POT events for individual threshold values (expressed as a function of multiples of standard deviation of daily precipitation amounts *s*) is shown in Fig. 2 in terms of average values over all control RCM runs. The tests are evaluated at the 0.05 significance level, which means that (assuming independence of the individual tests) one may expect that if the Poisson model is reasonable for the data, it is rejected in about 5% of cases.

For a dead-time of 1 day (minimum separation time between clusters of exceedances, maxima of which are considered the POT events), in JJA, the range of thresholds from 1.5 to 3 *s* leads to the fraction of tests rejecting the null-hypothesis close to 5% while the percentage becomes somewhat larger for smaller as well as larger thresholds. In DJF, the thresholds that meet the Poisson model assumptions start at 2.5 *s*, which, however, yields a relatively small seasonal frequency of POT events (less than 2 events per season in all model runs for the threshold of 2.5 *s*, declining for larger thresholds) and instability on the mean residual life plot. This indicates that heavy precipitation events in the RCM outputs tend to be more clustered in DJF than JJA, in accord with observations, and we decided to increase the dead-time to 2 days in DJF. With this option, the percentage of tests on DI rejecting the null-hypothesis is favourably reduced to a value close to 5% for all thresholds from about 1.5 *s* (Fig. 2 bottom). We decided to keep the same range of thresholds from 1.5 to 3 *s* also in DJF; for thresholds exceeding 3 *s*, the mean seasonal frequency of POT events with the dead-time of 2 days is very low (below 1.3 in all model runs), which leads to a large variance of the estimates of the GP distribution parameters. The choice is confirmed also by the mean residual life plot which starts to be unstable for thresholds above 3 *s* in some RCMs (not shown).

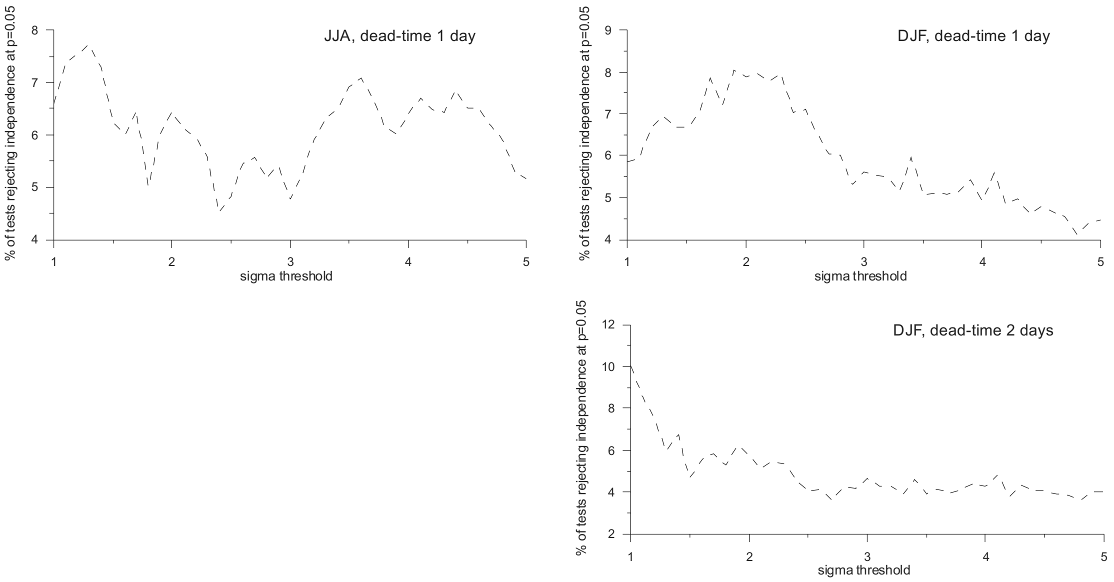

Figure 2. Percentage of tests on dispersion index (DI) rejecting the null-hypothesis on independence of POT events for individual threshold values (expressed as a function of multiples of standard deviation of daily precipitation amounts). Average values over all control RCM runs are shown.

Scenarios of changes in 50-yr return values of daily precipitation

Relative changes between the late 21st century scenario and control climate (1961-1990) of the 50-yr return values of daily precipitation amounts (as well as of mean seasonal totals) are shown in colour figures available at http://www.ufa.cas.cz/html/climaero/kysely/2007_Helsinki.html; averages over all gridboxes in the area under study in individual model runs are summarized in Table 1.

General features. The RCMs do not yield uniform spatial patterns of changes in heavy precipitation in neither JJA nor DJF; the inter-model variability is large, pointing to the fact that the particular formulation of an RCM (including parameterization schemes) plays an important role. In both seasons, increases in heavy precipitation prevail; they are more obvious and spatially less variable in DJF than JJA. There are no consistent differences between the two SRES emission scenarios; in some RCMs, the B2 scenario leads to generally less widespread increases compared to A2 while in others the opposite is observed. The intra-model variability (within ensembles of 3 SRES-A2 simulations for HadRM and HIRHAM) is generally larger than the differences between the A2 (ensemble mean) and B2 scenarios. A huge uncertainty within an ensemble of simulations run under identical forcings and boundary conditions is particularly conspicuous for HadRM in JJA. Differences between scenarios obtained with different driving GCMs for the RCAO model are pronounced in JJA (the ECHAM GCM leads to much drier conditions) but they almost disappear in DJF. For the ARPEGE model, differences between scenarios based on the two external forcings are only moderate in both seasons and appear to be less important than those related to different emission scenarios in the model runs.

Summer (JJA). In JJA, the spatial patterns are more influenced by random sampling variability (heavy daily amounts are related usually to convective clouds that may affect relatively small areas of a few hundred square km only), and very little coherent mixture of positive and negative changes appears in some RCMs. The projected changes are mostly insignificant; however, this is not true for the high-resolution HIRHAM output which yields coherent areas with large and statistically significant increases in the western part of the area (there is no gridbox with a significant decrease in this RCM while in 99 out of the 374 gridboxes in the area, the 80% confidence intervals of the 50-yr return values in the scenario and control runs do not overlap). The mean relative increase over the whole area under study is +40% in the high-resolution HIRHAM. Smaller regions of significant increases appear in the western part of the area (the Elbe river basin) in several other model runs, too (HIRHAM, CHRM, PROMES, RCAO) while they are absent in any RCM in the eastern part (the Odra and Danube river basins). This may indicate that the positive changes in heavy precipitation in JJA are more likely in the Elbe than Odra/Danube river basins, which may have also implications into decisions on flood prevention measures.

Winter (DJF). The projected increases in heavy precipitation are more uniform and general in DJF compared to JJA, although there are still model runs in which decreases prevail (HadRM and ARPEGE under B2 scenario). The mean relative increases (averaged over the whole area) exceed +40% in RCAO, a model that yields almost uniform positive change, and they are above +20% in 14 out of the 24 future runs. Significant declines in heavy precipitation do not appear in any RCM output, which indicates some robustness of the projected change. Opposite to JJA, the coherent areas of significant positive changes occur largely in the eastern part of the Czech Republic (the Odra and Danube river basins). The regions of significant positive changes tend to be much larger and more coherent in DJF compared to JJA.

Table 1. Mean relative changes of 50-yr return daily precipitation between the late 21st century scenario and control climate (1961-1990) in individual model runs, averaged over all gridboxes in the examined area. A2/B2 stands for the SRES emission scenarios; # denotes ensemble member. A driving GCM is given in parentheses if different from the HadAM/HadCM model.

RCM	JJA [%]	DJF [%]	RCM	JJA [%]	DJF [%]
HadRM, A2, #1	-4.8	19.2	RCAO (ECHAM), A2	-12.5	24.7
HadRM, A2, #2	5.6	24.3	RCAO (ECHAM), B2	3.1	45.6
HadRM, A2, #3	21.9	14.1	RCAO, A2	33.0	45.5
HadRM, B2	-7.1	-3.9	RCAO, B2	9.5	42.9
HIRHAM, A2, #1	36.8	21.3	ARPEGE, A2	6.6	19.7
HIRHAM, A2, #2	33.0	32.2	ARPEGE, B2	21.8	-1.7
HIRHAM, A2, #3	17.3	26.9	ARPEGE (ARPEGE), B2	10.6	6.4
HIRHAM, B2	27.3	14.5	CLM, A2	16.4	16.6
HIRHAM, A2, high-res	39.6	17.5	RegCM, A2	18.3	28.9
CHRM, A2	47.8	20.7	RegCM, B2	18.4	35.2
PROMES, A2	43.5	20.4	RACMO, A2	35.6	18.9
PROMES, B2	22.5	24.9	REMO, A2	40.8	25.0

DISCUSSION AND CONCLUSIONS

A peaks-over-threshold analysis with increasing threshold censoring was applied to regional climate models outputs in order to estimate climate change effects on probabilities of extreme daily precipitation. Based on the evaluation of a set of 24 scenario runs and 16 control runs of 10 RCMs over the area of the Czech Republic (central Europe), heavy precipitation events are likely to increase in severity in DJF and (with less agreement among models) also in JJA in a warmer late 21st century climate. The scenarios of changes in heavy precipitation are of the same sign as those in mean seasonal totals in DJF while they tend to be of the opposite sign in JJA. The generally drier conditions in summer may play a pronounced role in the development of floods, as reduced water infiltration capabilities of a dry soil combined to enhanced heavy precipitation amounts may increase peak river discharges and flood-related risks in the area.

The present study also shows that current RCM outputs should be interpreted with caution as regards changes in heavy precipitation at least in central Europe, since large inter-model differences appear in the future projections. The results for the late 21st century climate are much more model-dependent in JJA than DJF due to the enhanced role of the RCM formulation on the simulated changes (cf. Frei et al., 2006). Large differences in future scenarios of heavy precipitation appear also among ensemble members of a given RCM with a single SRES-A2 emission scenario and the same driving GCM.

The magnitudes of the projected relative increases are comparable in JJA and DJF, latter being the season when a relatively robust pattern of a positive change emerges in RCM runs. Nevertheless, as increases are projected to be more likely also in JJA, which may severely impact on society and ecosystems due to related increases in the frequency and magnitude of floods, much attention should be paid to a further development of RCMs (in terms of both increasing horizontal resolution in order to better reproduce orography and land use, and enhancing physical parameterizations employed) and a subsequent refinement of the future scenarios. In the current set of RCMs (except for the high-resolution HIRHAM), model orography fails to capture some important regional features.

We also point to the fact that the increases in high quantiles of precipitation in JJA are more coherent and statistically more significant in the high-resolution HIRHAM model compared to any other (lower-resolution) RCM output, which may be related to a better representation of orography. Since several RCM studies showed that increasing resolution leads to a generally better simulation of precipitation statistics, the possibility of future increases in heavy precipitation also in summer over central Europe, despite the overall decline in mean precipitation as well as the current lack of agreement in the pattern of change among RCMs, must be considered as a serious threat with severe implications into water resources management and flood-risk assessment and prevention.

ACKNOWLEDGEMENT

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[1] Anticipatory adaptation is the “adjustment [undertaken in advance] by a system to moderate the impacts of climate change, to take advantages of new opportunities or to cope with the consequences” (Adger et al., 2003, p.15). Adaptive capacity is defined by “the set of resources (natural, financial, institutional or human, and might include access to ecosystems, information, expertise, and social networks) available for adaptation, as well as the ability or capacity of that system to use these resources effectively in the pursuit of adaptation,” (Brooks and Adger, 2004, p.168).

[1] “Subjective self awareness if when consciousness is focused exclusively upon the self and the individual attends to his conscious state, his personal history, his body or any other personal aspects of himself” (Duval and Wicklund, 1972, p.2). Objective self awareness is when an individual’s consciousness is directed towards external objects such technology, money, entitlements, access to formal and informal social networks etc (IPCC, 2001).

Coping with future floods –
the Finnish flood mapping procedure currently under construction

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ABSTRACT

Climate change is believed to have a substantial impact on river floods in the coming decades due to changes in hydrologically relevant parameters, temperature, precipitation and snow cover. A comparable impact may result from projected changes in catchment land-use and river channel management. In order to minimize flood hazards, societies need to be better prepared for flooding in the future. This can be achieved by production of accurate flood scenarios and flood maps, and by effective dissemination of this information to relevant stakeholders. These include e.g., landowners, public employees, business companies and rescue services. We present the Finnish system for flood damage prevention, which involves hydrologic and hydraulic modelling supported by high-accuracy DEM, involvement of relevant databases for infrastructure and population for the inundation area, GIS techniques for spatial database management, cartographic techniques for visualization, and interactive stakeholder involvement. The Finnish flood mapping system parallels with the EU flood directive currently under final preparation. Key components in a successful flood mapping strategy include 1) cost-efficiency in relation to the data demand vs. accuracy of the final product (to allow mapping over large regions), 2) cartographic design in terms of both printed maps and digital GIS layers (for different end-users), 3) appropriate scale on which the map will be made public (to give necessary information but to discourage over-interpretation), 4) effective dissemination of the flood risk maps in an appropriate and accessible format to different stakeholders from planners and engineers (long-term need) to rescue services (acute need). It is becoming more and more evident that the best end-product for operative stakeholders will not be a static printed map layout, but a combination of relevant GI dataset layers selected from a flood information system by the end-user himself.

INTRODUCTION

Floods are natural phenomena which cannot be prevented. However, human activity is contributing to an increase in the likelihood and adverse impacts of flood events (EC 2006). Modern societies consider floods as serious natural hazards largely due to the fact that settlements and other infrastructure are commonly located on flood-prone areas along rivers and coasts, and are therefore fragile when water levels rise above normal. Societies prepare themselves against flood hazards by constructing various flood defence barriers, dams and embankments to protect existing infrastructure. In land use planning, the possibility of flooding needs to be taken into account in order to avoid ill-justified placement of infrastructure. In both situations, information of potential hazardous floods, for example their extent and probability, is fundamental for minimising risks and supporting cost-effective defence measures.

Historical data are invaluable in estimating future inundation, but various modelling applications are rapidly replacing or adding on to simple observations. Models also help tackle the changing conditions, i.e. that inundation characteristics will be different in the future as catchments and the hydrological cycle alter due to changes in climatic parameters and land use, and the spontaneous evolution of river channels and coasts.

Map format offers a useful and practical way of illustrating inundation under various potential or hypothetical circumstances. Map allows fast access to spatial flood information and is easy to interpret also by non-professionals. However, the style, format, information content and scale of flood map depend greatly on the needs of the end-user as well as the local circumstances. The desired accuracy of the mapping depends significantly on the topography of the modelled area, as on flat relief even small inaccuracies cause large differences in the spatial inundation pattern. Therefore, preparing an appropriate map is a demanding task.

European Union has prepared a directive on the assessment and management of floods (EC 2006), which steers the implementation of national mapping exercises. The paper at hand summarises the currently ongoing flood mapping procedure in Finland and briefly discusses the various options available in the map design

FLOOD MAPPING – BACKGROUND

Floods occur in Finland typically as a consequence of three key processes, each of which has a specific regional pattern. First, substantial spring floods due to snow melting dominate in northern Finland where snow cover is thick and spring arrives rapidly releasing large amounts of melt water. Second, torrential summer rain events cause flooding mainly in relatively small catchments along the coasts. The third main type of flooding occurs in the lake district of south-eastern Finland, where subsequent wet years may rise water levels beyond the regulation potential. In addition to these flood types, sudden ice jams may build during the early winter icing period as frazil ice formation, or during the spring ice break-up as ice block jams.

Systematic monitoring of lake levels and river discharges started in Finland as early as in the mid-1850's (Eloranta 2004), but became a standard procedure by the Hydrological office only in the 1960's. This early work was, however, only scarcely applied in flood mapping showing the extent of actual, monitored floods, so-called *historic flood map* (see Fig. 1). Predictive flood maps that show future projections have been produced during the last few years only (e.g. Rovaseutu flood map, Huokuna & Jaakonaho 2003). These maps present the extent and depth of statistically infrequent great floods (1/100–1/1000 year recurrence).

Catastrophic floods with casualties or severe economic damage are practically non-existing in Finland. The largest flood in the known history occurred in 1899 in the south-eastern lake district inundating 150,000 ha of shorelines, probably as a consequence of multiple underlying reasons, thick snow cover, late arrival of spring and heavy rains during the melting season (Kuusisto 1987). It has been estimated that similar flood today would cause economic damage of ca. 560 million euro (Ollila et al. 2000). Large floods have occurred every now and then since, and in the years 2004 and 2005 Finland has faced rather serious floods. In 2004, floods were triggered by summer-time rain storms whereas in 2005, southern Finland experienced winter flooding coincided with high sea levels, and parts of Lapland suffered from spring floods.

Growing concern about flood hazards persuaded the Ministry of Agriculture and Forestry to establish a committee on flood hazards for a period 2001–2003 (Timonen et al. 2003). The committee designed a strategy for the years 2003–2015 of how to tackle the flood problem. Almost simultaneously, the European Union initiated preparation of directive on the assessment and management of floods. The rationale was to give member countries a common guideline of how to improve preparedness against flood hazards. The directive has been approved by the commission in April 2007, and will come into effect in the near future. In practice, these two documents steer the research and policy on floods in Finland.

The principles of flood mapping can be defined in many different ways. In its simplest form, flood map presents the outline of the inundation area for a given water level, often referred to as *general inundation map* (Fig. 1). The information needed for inundation map includes ground level, in practice a digital elevation model (DEM), plus water level. Water level is often given for certain flood return period, e.g. 1/100 or 1/250 years. It may be based on linear interpolation between gauging stations, or on more sophisticated methods, such as hydraulic modelling, which may produce more realistic water levels especially in complex channels or flat terrain. Combined with a base map, this type of data are usually referred to as *flood hazard map* (Fig. 1) offering a valuable tool for long- and short-term flood preparedness. Sometimes, however, more information is desired on potential flood hazards, such as vulnerability data in the form of the number of people affected, or the involved potential economic damage. A map presenting this type of more detailed information is referred to as *flood risk map* (Fig. 1).

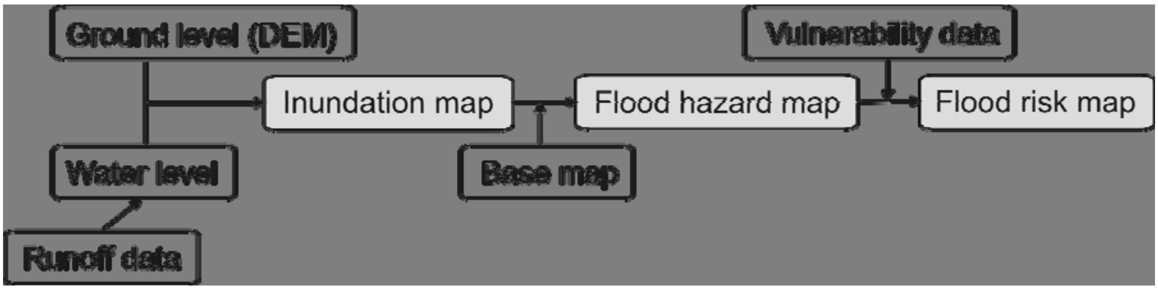

Figure 1. The standard categories of flood maps showing the respective levels of information.

The prediction, modelling and mapping of floods becomes more complicated when one projects the simulation in the future by including the factors of climate change, land use change, and both spontaneous and human induced alterations in channel form. Climate change, although highly complex, can be predicted with specifically designed climate models. At present, the mean annual temperature in southern Finland is +5 °C, whereas in the north it is –2 °C. The snow cover period varies from 110 days in the south to 220 days in the north. The predicted climate change may alter these conditions quite dramatically. Based on regional climate models (e.g., RCAO-model, Rummukainen et al. 2001) the mean temperature will rise 4–5 °C in winter and 2–3 °C in summer, with annual precipitation increase of 20–30%. Of crucial interest will be the snow conditions in the future, as the occurrence of permanent snow will reflect the supposedly semi-linear temperature change in a non-linear (snow / no snow) manner. For further information of flood scenarios under changing climate, see the paper by Alho et al. in this volume.

Projecting changes in land use and infrastructure is most challenging task, as human behaviour and decision making depend on numerous inter-dependent and independent variables. Land use planning follows demographic changes and land demand e.g., for building purposes but is, however, increasingly controlled by counteracting pressures such as nature protection, cultural heritage, and other soft values. Increased understanding of the operation of natural systems, such as spontaneous channel evolution, may help in flood defence measures. Dams, embankments and other hard-engineering measures may sound justifiable in short term but involve risks, should the river suddenly respond unpredictably to these alterations. Therefore, scenarios on human induced changes on watersheds are crucial, but have to be limited to a foreseeable future, typically in the order of 20–30 years. For mapping purposes, a similar time span may be justifiable.

FLOOD HAZARD MAP

As the first step in the contemporary Finnish flood defence strategy, the flood hazard maps were implemented as modus operandi in 2005 (Sane et al. 2006). The map design was based on scientific studies on various background parameters such as accuracy assessment of both the DEM and the water level estimation. The standard procedure for map preparation was published as a hard copy manual (Sane et al. 2006) and as an updatable intranet resource for authorized use. The key principles in map design included cost-efficiency, relatively straightforward production, and dependency only on existing, readily available databases. The construction of Finnish flood hazard maps is based on decentralised production in regional environment centres for their own administrative areas. Preparing the maps "at the site" allows input of local knowledge in the map making procedure, but requires staff briefing and education for those involved in the process.

As the EU directive on floods was known to come into effect in the near future, the aim in the Finnish map design from early on was to try and respond to the directive's requirements although details of the contents were still under discussion. The accepted version of the directive (EC 2006) states about flood hazard maps as follows (Chapter III, Article 6):

> *Paragraph 3: Flood hazard maps shall cover the geographical areas which could be flooded according to the following scenarios:*
> *(a) floods with a low probability, or extreme events scenarios;*
> *(b) floods with a medium probability (likely return period ≥ 100 years);*
> *(c) floods with a high probability, where appropriate.*

and

> *Paragraph 4: For each scenario referred to in paragraph 3 the following elements shall be shown:*
> *(a) the flood extent;*
> *(b) water depths or water level, as appropriate;*
> *(c) where appropriate, the flow velocity or the relevant water flow.*

In other words, the directive requires flood maps for three different water levels, and for each level, the extent, depth and flow velocity should be presented. In Finland, flood hazard maps are prepared for at least two water levels with return periods 1/100 and 1/250 years, as these are related to the lowest allowed building levels. In addition, return periods of 20 and 1000 years are often constructed alongside the standard ones.

Two different mapping scales are applied in Finland, namely coarse-scale and fine-scale, designed for different regional needs and purposes. Coarse-scale map forms the baseline standard on 1:50,000 scale at maximum, but may be prepared on smaller scale e.g., on 1:250,000 for large areas. The water level information for coarse-scale maps is based on linear interpolation between gauging points, and the applied DEM is the standard 25-metre national grid. The end product is, hence, indicative only and does not include any details of the infrastructure.

Fine-scale flood hazard maps are typically on a scale 1:20,000. They also utilise more accurate DEM, which has been derived using multiple datasets such as map contours, municipal elevation points, airborne laser-scanning or, where applicable, specifically collected elevation information (e.g., RTK-GPS data). Water level on fine-scale maps is based on one-dimensional, or in specific cases two-dimensional, hydraulic modelling. The end product is considered reasonably reliable, and may show individual buildings and other details. Scale and detail matters are of importance, as one has to carefully consider the appropriate scale on which the map will be made public to give necessary information but to discourage over-interpretation.

FLOOD RISK MAP

Fine-scale flood hazard map can be interpreted for qualitative potential damage if the end-user is a competent map-reader and/or has local knowledge. It is not possible, however, to estimate quantitative damages or the number of affected persons a hazard map, or get information of e.g., hazardous targets such as chemical factories as they are often not identifiable on map. For these purposes, it is desirable to construct flood risk maps which include information of regional vulnerability (see Fig. 1). Flood risk map will be useful also for estimating justifiable proactive flood defence measures as it allows cost comparisons between various hypothetical inundation patterns versus construction alternatives.

The accepted version of the flood directive (EC 2006) lists four key parameters that should be included in flood risk maps, as follows (Chapter III, Article 6):

> *Paragraph 5: Flood risk maps shall show the potential adverse consequences associated with flood scenarios referred to in paragraph 3 and expressed in terms of the following:*
> *(a) the indicative number of inhabitants potentially affected;*
> *(b) the type of economic activity of the area potentially affected;*
> *(c) installations as referred to in Annex I to Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control which might cause accidental pollution in case of flooding and potentially affected protected areas identified in Annex IV(1)(i), (iii) and (v) to Directive 2000/60/EC;*
> *(d) other information which the Member State considers useful such as the indication of areas where floods with a high content of transported sediments and debris floods can occur.*

The Finnish flood risk map scheme has been designed based on the EU directive and national preconditions, plus the availability of datasets and other information. In practice, the risk map is based on the fine-scale hazard map, which acts a base map, overlaid with other data as extra layers in a GI (geographic information) system. Finland is in a fortunate position in that existing GI databases on various societal matters are rather well developed and comprehensive. It is therefore possible to construct flood risk maps based on existing data layers without the need to build them manually for mapping purposes only. The standard procedure for flood risk mapping is summarised in Fig. 2. For further details on flood risk mapping based on two pilot cases, see the paper by Harilainen et al. in this volume.

The fact that the flood mapping procedure is undertaken in digital format with the aid of GIS software overrules many hindrances related to conventional manual operation and hard-copy maps. It is becoming evident that the best end-product for stakeholders will not be a static printed map, but a combination of relevant GI dataset layers selected from a flood information system by the end-user himself. Map construction within the GI-system means that the somewhat artificial division between flood hazard and flood risk maps may dissolve in time. This allows flexibility but requires GI-competence from the user. At the moment education is required to overcome the lacking competence but in time, GI competence may become a standard skill.

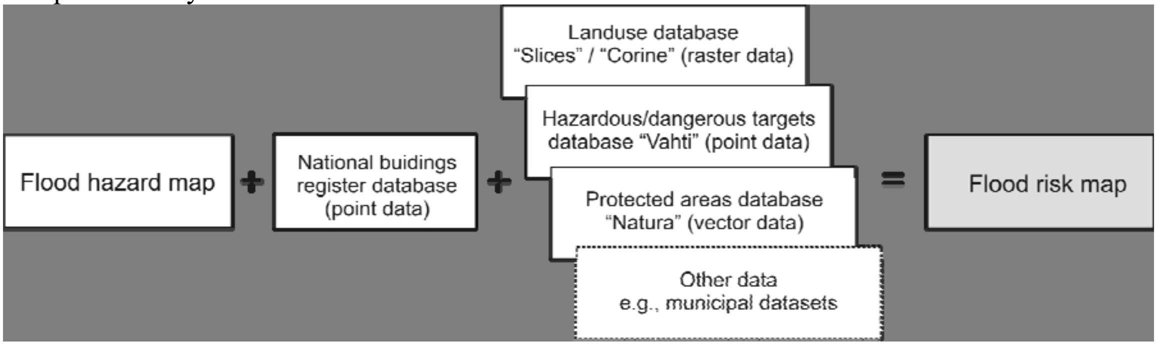

Figure 2. Flood risk map is based on existing flood hazard map plus selected further datasets.

In the meanwhile, care has to be taken that flood maps are available as ready-made end products for those end-users who cannot or do not have time to prepare maps themselves. In many acute occasions, such as evacuation of flood affected persons, printed maps may be the only feasible format.

The Finnish flood maps, or rather their raw material in the form of necessary GI datasets, are an integral part of the governmental flood information system *(Tulvatietojärjestelmä),* which is available for all relevant end-users from rescue services to land-use planners. In addition, generalised versions of flood maps may be made available for public via the internet. Digital format also allows easy and automatic updating of data layers as information of flood parameters increases and understanding of the underlying processes improves.

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The impacts of climate change on the mountain glaciers of the central Andes, and the future of water supply in Lima, Perú

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Keywords: Lima, Perú, water supply, climate change, aquifer, interbasin transfer

ABSTRACT

Perú is a land of extremes of climate and topography. Spanning the Andes mountain chain, climate ranges from desert conditions along the Pacific coast; to tropical rainforest in the headwaters of the Amazon River in the east. Between these extremes are the varied environments of the Cordillera. The Andes are the second highest mountain range in the world, and Perú has the greatest amount of glaciers of any tropical country.

Population of Perú has surpassed 28 million, with nearly 70 % living on the arid to semi arid western coastal plain. Lima, a city with more than 8 million, people has struggled to provide basic water and wastewater service to a rapidly expanding city. The municipal utility, Sedapal, is dependent upon surface water runoff from the mountains, and on numerous wells drawing upon aquifers with rapidly declining water levels.

In a desperate attempt to increase supply, Sedapal has undertaken an ambitious and expensive program to obtain the waters of lakes and wetlands of the eastern slope of the mountains. These reservoirs, and tunnels through the Andes, will, they hope, provide a secure supply through 2015. But the glacial ice of the mountains, which sustain flow to the rivers and lakes, have been rapidly decreasing in mass; with a loss of nearly 23 % in the last 30 years. They are receding as a result of increasing temperature and many are likely to disappear entirely within the next 50 years. Completion of the trans-Andean tunnels will help Sedapal to supply Lima for the near term, but a significant change in the amount of system water loss and usage patterns will be required to sustain the city's supply for the future. The extent to which climate change will impact water supplies in Perú is uncertain, but it is difficult to be optimistic. It is time to face the future.

INTRODUCTION

Perú spans the Andean Cordillera and has highly varied topographic regions and very diverse ecological zones. Located along the west coast of South America, from 3 degrees to 18 degrees south latitude; Perú's climate ranges from desert areas along the Pacific coast, to tropical rain forest of the Amazon basin in the eastern interior. Between these extremes lie a number of narrow north-trending cordilleras, which rise to elevations well above 6000 meters (Figure 1).

Although located in tropical latitudes, Perú's mountains contain the largest volume of glaciers in any tropical region of the world. Melting of these ice masses results in significant fresh water flow in the nation's rivers; even during the extended dry season from April through October. Most of the rivers draining the Peruvian Andes are tributary to the Amazon River. Rivers flowing down the steep western slope of the range to the Pacific Ocean have limited drainage basins and only those which drain glaciated ranges have sufficient water to provide for irrigation agriculture year round.

Today the population of Perú is more than 28 million, and more than 70 % are living along the western coast. These coastal cities rely on water flowing to the Pacific from the mountain regions; and on ground water well systems to provide fresh water resources. Lima, with nearly one-third of Perú's population, has grown beyond its water supply capabilities. In recent years the Lima water utility, SEDAPAL, has begun importation of water from reservoirs in the mountainous basin to the east; with the expectation that glacial meltwaters will recharge the lakes and reservoirs of these regions. Expansion of these collection systems is currently underway, with a phased set of projects known as Marca I-IV.

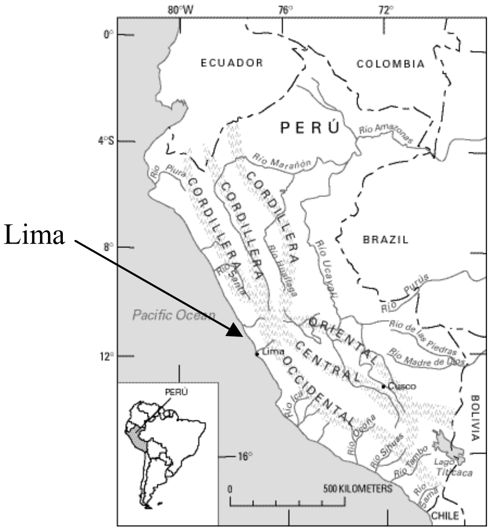

Figure 1. Location map of Perú, and the major cordilleras and rivers. Lima is located on the Pacific coast in central Perú. (USGS PP 1386 I-4)

CLIMATE OF PERU

Perú is located on the western margin of South America, and normal weather patterns travel from the Atlantic and across the Amazon Basin, dropping most of their moisture as rainfall over the Amazon. The Andes provide a high barrier to migration of moisture further west, and snows fall on the easternmost cordillera with little moisture reaching the western ranges. The continental divide between the Atlantic drainages and those flowing to the Pacific is located less than 125 km from the Pacific, consequently most runoff is toward the Amazon Basin.

Rainfall is highly seasonal throughout Perú with most of the annual precipitation coming during the austral summer (November-April). In northeastern Perú monthly rainfall typically exceeds 400 cm, but for much of Perú the annual precipitation is well below 50 cm. The cold Humboldt Current travels north along the west coast of South America from Antarctica, effectively inhibiting rainfall along the coast. Coastal southern Perú is one of the driest places on Earth, with rain coming on average only once in 10 years. Lima receives an average of less than 20 mm of rain per year, although for much of the winter a fog hangs over the coast.

Perú is the home of El Niño, the periodic reversal of Pacific Ocean currents which causes a pooling of warm water along the coast of Perú. Strong El Niño events affect the weather worldwide, and can bring substantial rain and flooding to coastal Perú; causing severe erosion and destruction of infrastructure and crops. La Niña, an event which causes the coastal waters to be colder than normal, also can cause significant changes in the weather, with the mountains of southeastern Perú receiving colder temperatures and increased precipitation.

The seasonal nature of rainfall throughout Perú is well illustrated by the Rio Rimac (Figure 2), which supplies most of Lima's water supply, and drains the glaciated highlands of the Cordillera Central. Although annual precipitation near its headwaters averages between 600-1000 mm, during the extended dry season discharge of the river averages less than 20 m^3/s.

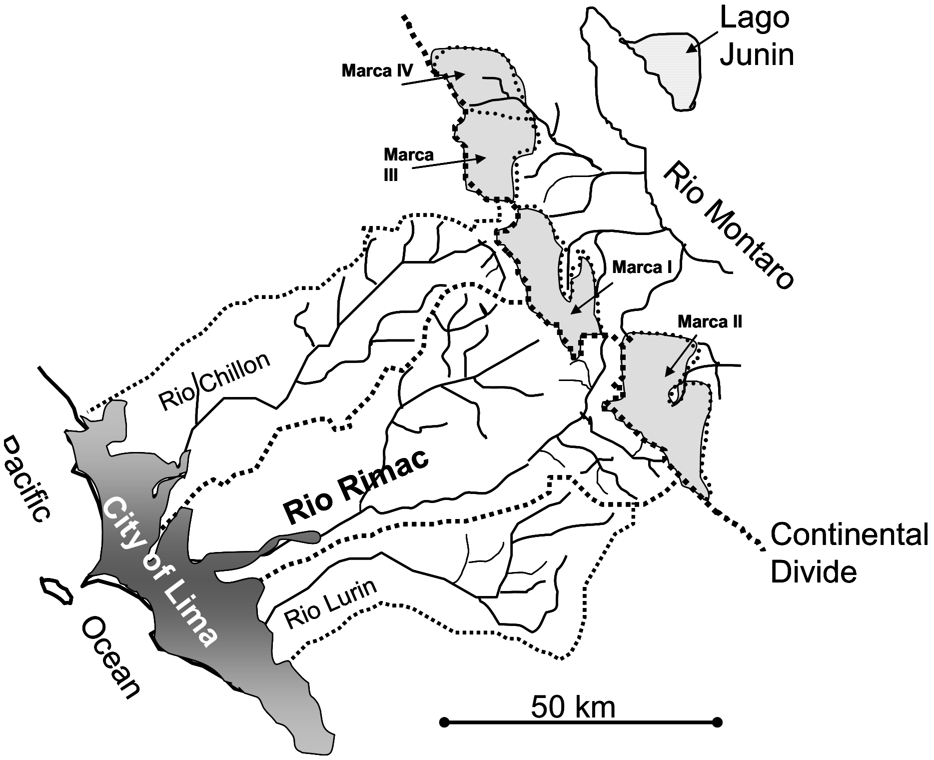

Figure 2. Lima area and the Marca I-IV water system enhancements.

LIMA'S WATER SUPPLY SYSTEM

Colonial Lima is located on the narrow coastal plain of the Pacific, and is one of the oldest cities of the Americas; founded in 1535, shortly after the conquest of the Incan Empire by the Spanish. It has a European look and bustles with activity and a rapidly growing population. In the 1930's the population was only 300,000, but today is greater than 8 million people. Nearly half of those have arrived from the country during the last 30 years, and the city struggles with infrastructure to support this rapid growth. The original small colonial town is located along the south bank of the Rio Rimac and public water supply from the river was initiated in the late 1500's. For many years this was adequate, but the natural flow of Perú's coastal rivers is diverted for irrigation, power and supply upstream. During the dry season many rivers dry up completely.

The Pacific coast of Perú is tectonically active, with frequent earthquakes, and mountains more than 6000 meters in elevation just 120 km inland. The average gradient of the Rio Rimac is more than 3 %; and it flows from the wetlands, lagunas and glacial meltwaters of the Cordillera Central through steep narrow valleys onto a clastic wedge of coarse alluvial sediments between the mountains and the coast.

Today Lima has sprawled across three coastal basins (Figure 2), and the city continues to grow with the addition of Pueblos Jovenes (Young Towns). These additions begin with minimal infrastructure planning and the hope that utilities will follow. Most of this expansion has been to the north into the Rio Chillon basin; and a ground water and surface water treatment plant has been added at the northernmost part of the distribution system. The city has also expanded to the south and southeast into the Rio Lurin basin, and plans are in place for a new distribution system to be developed there also. The potential supply from these marginal basins is limited due to their small size and lack of significant recharges areas high in the Andes.

Nearly 75 percent of the water supply of Lima today is from the discharge of the Rio Rimac (32 m^3/s), which is diverted nearly in its entirety and treated for distribution at La Atarjea, several kilometers upstream of Lima central. 454 wells are connected to the distribution system throughout the network, but only about 232 are in service at this time (Lopez, 2004). These wells supplement the surface supply of the Rimac with nearly 8.5 m^3/s of water, but the aquifers vary in quality; and have been overexploited, resulting in rapidly falling water levels. Local contamination issues result both from land usage, wastewater infiltration and salt water intrusion in many areas, and have forced abandonment of numerous wells. In addition to SEDAPAL's wells, nearly 2270 large private wells supply industry and several municipalities, resulting in an unsustainable exploitation of the aquifer.

Total supply of the Lima water system averages 42.5 m^3/s today. The population served in 2005 was estimated to be 7.3 million, with service averaging 23 hours per day. More than one million people in Lima are not served by SEDAPAL and are forced to buy water from haulers at highly inflated rates. Plans to expand water supply to the Lima distribution network are focused on supplementing flow of the Rio Rimac. Precipitation in the highlands where the river has its origin is significant, and during the wet season more than 12 m^3/s bypasses La Atarjea and flows to the sea. Reservoirs have been developed in the upper basins of Rio Santa Eulalia and Rio Blanca, the two rivers which contribute the bulk of Rio Rimac's discharge.

In the mid 1990's a set of projects was conceived to augment the supply to each of these two sub basins by constructing aqueducts to bring water from across the continental divide from the headwaters of the Rio Montaro, in the Department of Junin. This staged project (Marca I-V) would modify existing lagunas into storage reservoirs and gather the resources of the headwaters of the Montaro and its tributaries with canal systems (Figure 2). Water would then be transferred by tunnels across the divide into the basin of the Rimac. The first portion of this system was completed in 1997 when the Marcapomacocha reservoirs were connected to the headwaters of the Rio Santa Eulalia. Marca III consists of a series of gathering canals and tunnels to bring water from additional lagunas south to Marcapomacocha to enhance the available water for transfer across the divide and into the Rimac basin, and was completed several years ago. At present, another enhancement (Marca IV) is to be added to connect the large Laguna Huascacocha to Marcapomacocha. Work on this project is to begin in late 2007, with completion expected in 2009.

Enhancements to the Rio Blanca flow are to come from an ambitious project (Marca II), which will redirect the drainage from a portion of the glaciated Cordillera Central, southeast of the Rimac basin, which today is tributary to the Rio Mantaro. This will be done by collecting most of the flow of the Rio Yauli and directing it up basin to Laguna Pomacocha, and then into a new 10-km tunnel for transfer beneath the continental divide and into Rio Blanca. Marca II has been delayed since the late 1990's, but has been bid for development beginning later in 2007; and may be carried out concurrently with Marca IV. Together the new projects are expected to cost nearly US $150 million, and will add 7.2 m^3/s to the discharge of the Rimac.

In order to utilize the enhanced flow of the Rio Rimac at Lima, a new treatment plant is planned above the existing La Atarjea, which operates at capacity. The new plant at Huachipa is to have a capacity of 10 m^3/s, and will distribute water to the rapidly growing portions of the city to the north and south of Lima central. Huachipa is expected to cost US $130 million with an additional US $140 for water distribution lines.

President Alan Garcia, newly elected in 2006, has pledged to provide water for all of Lima's residents, and an aggressive campaign of improvements, "Agua para Todos (Water for All)", has begun. However, without the enhanced supply from the Marca projects (7.2 m^3/s) anticipated in 2011, Sedapal will not have enough water to meet the demand. Supply security beyond 2011 is dependent upon factors both within and beyond SEDAPAL's control. It has been estimated that the aging water distribution infrastructure loses as much as 40 % of its water; and the enhanced reservoirs of the Cordillera Central, on both sides of the continental divide, are dependent today on continued heavy rainfall during the wet season and on glacial meltwaters to supplement recharge of the reservoirs during the dry months. As recently as 2005, water supply in the city was impacted due to inadequate wet season recharge of the Marcapomacocha lagunas. Prolonged drought, and reduced glacial ice due to climate change, could severely restrict the water supply in the future.

IMPACT OF CLIMATE CHANGE

Peru has more glaciers in its mountains than any other tropical country, but the area covered by ice is rapidly decreasing. Estimates from aerial photography of the area covered by ice in the 1960s was 2041 km^2, but a second estimate in 1997 showed coverage of only 1596 km^2, a reduction of nearly 22 percent in less than 30 years (Ames, et al., 1989). One of the best documented glaciers in the Andes is the Qory Kalis outlet glacier from the Quelccaya ice cap in the Cordillera Vilcanota of SE Perú. This glacier has been measured by photogrammetric methods regularly since 1963 and has retreated steadily, with a greatly increased rate of retreat in recent years. Qory Kalis glacier may disappear completely within the next decade (Thompson, et al., 2006).

Ice cores recovered from Peruvian ice caps have yielded some of the best climate records of tropical South America during the Holocene Epoch, and indicate significant extended periods of drought; which have been correlated with major changes in the well-being of early civilizations and empires of the pre-colonial Americas (Moseley, 2001). Even more alarming have been discoveries of 5000 year-old plant remains uncovered by the recent retreat of the ice at Quelccaya, indicating that the ice mass has not been this small in the last five millennia.

Rio Santa, in Ancash Department north of Lima, is the longest river flowing to the Pacific Ocean and drains much of the glaciated Cordillera Blanca. This range has the highest mountains and the most glacial ice of any range in Perú. Rio Santa is one of the few west-flowing rivers to reach the sea during the dry season, and its flow is sustained by meltwaters from these glaciers. The glacial meltwater contribution to the discharge of Rio Santa has been estimated at approximately 40 % (Mark et al., 2005).

Much of the discharge of the lower Rio Santa is transferred to the north across three coastal rivers to supply the Chavimochic irrigation system, which waters important agricultural regions in the Viru, Moche and Chicama river valleys. This project has expanded irrigation agricultural in northern Perú and is the largest business of the Trujillo area. A decrease in the dry-season contribution of glacial meltwater to the Rio Santa will ultimately impact the irrigated areas. Hydroelectric power generation will also be impacted. Today the entire flow of the Santa is diverted to power the turbines at Huallanca during the months of June-September, and decreased flow in the future will limit the output of this and other important hydropower plants of the western slope of the Andes.

CONCLUSIONS

The concentration of Perú's population, industry and commercial agriculture along the narrow Pacific coastal plain poses sustainability issues for a future which promises warmer temperatures and limited glacial storage of water. Less meltwater contributions to the rivers will result in lower flow to the coast, and ultimately will impact irrigation, power generation and most importantly, drinking water supplies. SEDAPAL, Lima's public water utility, is in a race to increase supply from the mountains, to try to catch up to the cities rapid population growth. These costly projects are designed for the needs of today, but may not be adequate for the demands of tomorrow. Recharge of the mountain reservoirs is dependant on summer rainfall, and winter meltwaters from the glaciated peaks of the Cordillera Central. These glaciers are shrinking fast and will likely disappear within 50 years.

Extended droughts have been recurrent in the Andes and have severely impacted Inca and pre-Inca cultures. Return of severe drought conditions would certainly place serious restrictions on the ability of SEDAPAL to fulfill the promise of "Water for All" called for by President Garcia. This is not likely to be just a short-term concern. SEDAPAL must improve the efficiencies of their distribution system and press forward with the costly expansion plans of Marca I-V. Future presidents will struggle with water supply problems as well, and Lima, the largest city in the Americas to be sited in a desert, may have to turn to the sea for water supply. Where the nation will get the money or energy for desalination is a looming question.

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Effects of climate change on discharge behaviour of the river Rhine

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ABSTRACT

Recently, the Royal Netherlands Meteorological Institute (KNMI) presented four new climate scenarios for the Netherlands. These new scenarios will serve as the national standard in water management adaptation policies in the Netherlands for the coming years. The main part of the Rhine basin lies upstream of Lobith and outside of the Netherlands and thus the discharge regime of the Rhine is determined by its upstream hydrological behaviour. In the current paper the effects of climate change on the discharge of the river Rhine at Lobith are assessed, projecting the new KNMI climate change scenarios on the entire river basin. To do this, the semi-distributed conceptual hydrological HBV model for the Rhine basin was used. Transforming 35 years of historical climate forcing data generated the meteorological input series, which resulted in projected changes in mean discharges of the Rhine. In addition, with the aim to analyse effects on extreme events with return periods smaller than 1/200 years, output of a stochastic weather generator was used to create meteorological input series of 1,000 years for different climate scenarios, resulting in several sets of 1,000 years of daily discharge data.

INTRODUCTION

It is expected that climate change will have major implications for the discharge regime of the Rhine basin. Seasonal discharge will shift to more discharge in winter and less discharge in summer, and the frequencies of floods and droughts are expected to increase (Kwadijk, 1993; Middelkoop et al., 2001; Te Linde, 2006). Recent climate change research focuses on simulating changes in the magnitude and frequencies of flood events using different predictive models.

On 30 May 2006, the Royal Netherlands Meteorological Institute (KNMI) presented four new climate scenarios for the Netherlands (Van den Hurk et al., 2006) which are referred to as KNMI'06 scenarios. It is in the interest of Dutch water managers to have an idea of the impact of climate change on the discharge regime of the river Rhine and the question has risen whether recent adjustments in modeling methods and when using the new climate scenarios, will change existing expectations.

Recently, Van Deursen (2006) assessed the effects of climate change on the discharge of the river Rhine using the distributed grid-based model RhineFlow by projecting the KNMI'06 scenarios on the entire basin of the Rhine. The semi-distributed lumped HBV model has been used in multiple studies on discharge generation in the Rhine basin (Eberlet et al, 2005; Weerts & Van der Klis, 2004). It is for example used to run long time series, which can then be used to assess return periods of extreme events for the Rhine branches in the Netherlands. For this last application the precipitation is provided by a stochastic weather generator (Beersma et al, 2001).

In the current paper the HBV model for the Rhine is used to assess the effect of climate change on the discharge, using the KNMI'06 scenarios. Transforming 35 years of historical climate forcing data generated meteorological input series. This resulted in projected changes in mean discharges of the Rhine. In addition, with to aim to analyse effects on extreme events with return periods smaller than 1/200 years, output of a stochastic weather generator was used to create meteorological input series of 1,000 years for different climate scenarios

METHODS

The Rhine basin

The entire Rhine basin covers an area of 160,800 km2 upstream of Lobith, which is located at the Dutch-German border and where the river Rhine has an average discharge of 2,200 m3/s. The discharge is influenced by the amount and timing of precipitation, snow storage and snow melt in the Alps, the evaporation surplus during the summer period, and changes in groundwater and soil water storage (Pinter et al., 2006).

HBV

The HBV model (Hydrologiska Byråns Vattenbalansavdelning) (Bergström, 1976; Lindström et al., 1997) is a semi-distributed conceptual model that simulates discharge on a daily basis for 134 sub-basins of the Rhine. The model consists of different routines in which snowmelt is computed by a day-degree relation, and groundwater recharge and actual evaporation are functions of actual water storage in a soil box. Discharge formation is represented by three linear reservoir equations and the sub-basins are linked together with a simplified Muskingum approach to simulate routing processes. The HBV model was developed for the Rhine in 1999.

Rainfall generator and FEWS Extreme Discharges simulations

A historical data set for the period of 1961-1995 of daily temperature and precipitation data is available at 36 stations in the Rhine basin. Using nearest-neighbor resampling and these 35 years of historical data, the rainfall generator creates series of 1,000 years of synthetic precipitation and temperature values, which can then be used as input data for hydrological modeling of the Rhine basin. For a detailed description of the method, see Beersma et al. (2001).

FEWS Extreme Discharges (Werner & Reggiani, 2002) is instrumentation in support of determining the frequency of occurrence of extreme discharge events in the Rhine basin. Using the 1,000 years synthetic precipitation and temperature series as generated by the rainfall generator, 1,000 years of runoff is calculated using the HBV model. Rather than taking the traditional approach of fitting and extrapolating extreme value distributions, the approach taken here attempts to calculate these extreme value distributions using continuous model simulation, where the period of simulation is in the same order as the return period of the event of interest. The Gumbel distribution appears to fit best at extreme discharge values of the Rhine basin and is used as generalized extreme value distribution.

Climate scenarios

On 30 May 2006, the KNMI (Royal Dutch Meteorological Institute) presented four new climate scenarios for the Netherlands, which are referred to as KNMI'06 scenarios (Van den Hurk et al., 2006). These KNMI'06 scenarios will serve as the national standard in adaptation policies in the Netherlands for the coming years. General Circulation Model (GCM) simulations show changes in the strength of the seasonal mean western component of the large-scale atmospheric flow in the area around the Netherlands. That is why besides temperature, this circulation is used as steering parameter. Also potential evaporation is affected greatly by the assumed circulation change. The values chosen for global temperature increase and atmospheric circulation change are used as steering parameters to discriminate the four scenarios for the Netherlands, and are summarized in Table 1. In the current paper, only results are displayed and discussed of the G and W+ scenarios, which represent the mildest and the most extreme scenario, and by that means the spread of all four scenarios. No discrimination in probability exists between the four climate scenarios.

Table 1. Values for the steering parameters used to identify the four KNMI'06 climate scenarios for 2050 relative to 1990.

Scenario		Global Temp. Increase	Change of atmospheric circulation	
G	Moderate	+1 ºC	Weak	
G+	Moderate +	+1 ºC	Strong	- Milder and wetter winters due to more westerly winds - Warmer and drier summers due to more easterly winds
W	Warm	+2 ºC	Weak	
W+	Warm +	+2 ºC	Strong	- Milder and wetter winters due to more westerly winds - Warmer and drier summers due to more easterly winds

Delta approach

The different climate scenarios for the Rhine basin were constructed by applying simple transformation rules to observed temperature and precipitation, also referred to as the delta change approach (Lenderink et al., 2007). This simple delta approach for temperature just adds an expected temperature increase to the observed temperature record to obtain a future temperature series. Precipitation was perturbed by a fraction. These rules leave the present day variance of temperature and the coefficient of variation of precipitation unchanged. Also, changes in the number of precipitation days and potential changes in the correlation between different variables are not considered. Furthermore, the transformation was applied for the whole Rhine basin, not taking into account possible geographical differences.

The scenario time series are given by:

$$T_{scen,d*}(t) = T_{his,d}(t) + \left(\overline{T}_{scen,d} - \overline{T}_{his,d}\right)$$

$$P_{scen,d*}(t) = P_{his,d}(t) \times \left(\frac{\overline{P}_{scen,d}}{\overline{P}_{his,d}}\right)$$

where T_{scen} is the scenario temperature in ºC, T_{his} the historical temperature in ºC, P_{scen} the scenario precipitation in mm, P_{his} the historical precipitation in mm, $d*$ the day in future time series and d the day in reference time series.

Evaporation in HBV is implemented by a file describing mean monthly values of potential evaporation for all HBV sub catchments. To transform the evaporation data this file was perturbed by a fraction.

RESULTS

Results are available for several locations (Te Linde, 2006) of which only results at Lobith are displayed and discussed in the current paper. Mean monthly discharges and changes in extreme value distributions are presented for the G and W+ scenarios. In the current paper, the generated historical discharges by HBV for the period 1961-1995 are not compared to the measured historical discharge for the period 1961-1995. Personal notes that do describe such a comparison (Buiteveld, 2005), show that HBV represents mean discharge values very well, but tends to overestimate discharge above 10,000 m^3/s at Lobith by +/- 10%.

Change in mean discharges

Figure 1 displays the predicted mean change at Lobith, both in absolute and relative values. The mean rise in discharge in the winter months December, January and February varies from ~ 200 m^3/s (8%) rise for the G scenario to ~ 400 m^3/s (16%) for the W+ scenario. In the summer months June, July and

August, the discharge changes only minor in the G scenario. The W+ scenario (remember the strong changes of atmospheric circulation) though, shows a decrease in mean discharge of ~ 750 m^3/s (42 %).

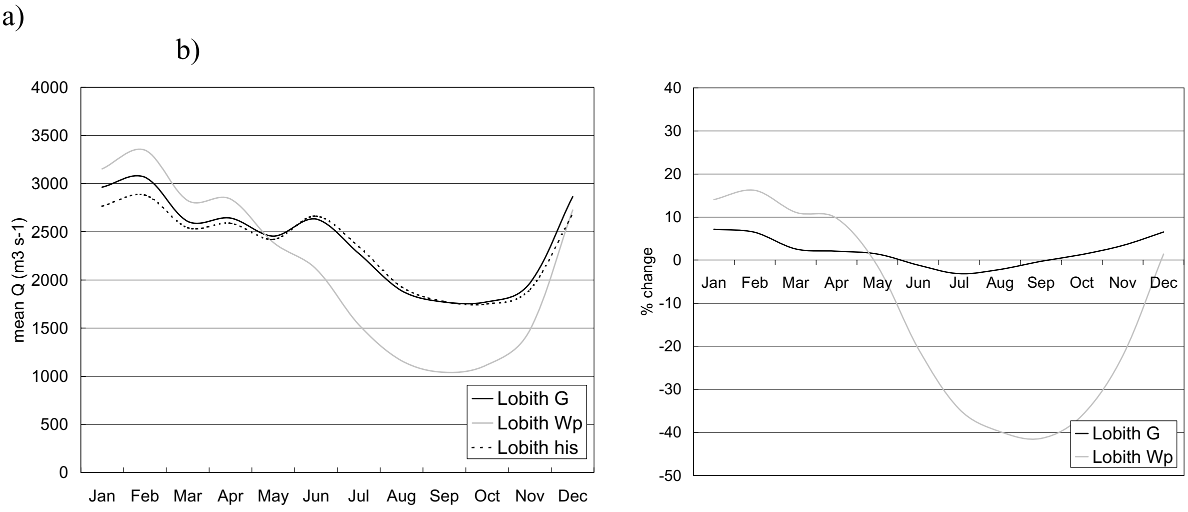

Figure 1. Mean change in discharge at Lobith, a) absolute values and b) relative values

Change in extreme value distributions

Figure 2 displays Gumbel plots of the yearly maxima of the simulated daily discharge at Lobith for 1,000 years of discharge based on 1961-1995 meteorological input data and the G and W+ climate scenarios input data. The W+ scenario shows the most extreme increase in extreme values when compared to the G scenario. Apparently all very extreme discharge events occur in the winter months, when the W+ scenario displays more increase in precipitation and temperature rise, than the G scenario does.

Also in Figure 2, a straight line displays the fitted Gumbel distributions. The Gumbel distribution is hereby fitted without threshold values. The fit therefore does not take into account the observed downwards bend of the most extreme values. The downward bend seems to include approximately the same extreme events for all scenarios, and does not occur at a fixed discharge value.

Table 2 shows a summary of the Gumbel extreme value distribution fit for the dataset representing the recent situation and the two climate scenarios. When looking at a return period of 1,250 years, the dataset based on the period 1961-1995 results in an estimated discharge of 18,349 m^3/s, which is more than 2,000 m^3/s higher than the currently adopted value of 16,000 m^3/s at Lobith that is based on 100 years of measured discharge values. This is due to the earlier mentioned way of fitting the Gumbel distribution without a threshold, which causes the fit to lie above the highest calculated discharges. The G scenario returns a discharge of 19,424 m^3/s at a return period of 1,250 years, which is 5.8% higher than the dataset based on the historical period 1961-1995. The W+ scenario returns a discharge of 22,076 m^3/s at a return period of 1,250 years, which is 20% higher than the dataset based on the period 1961-1995 and 13% higher than the G scenario.

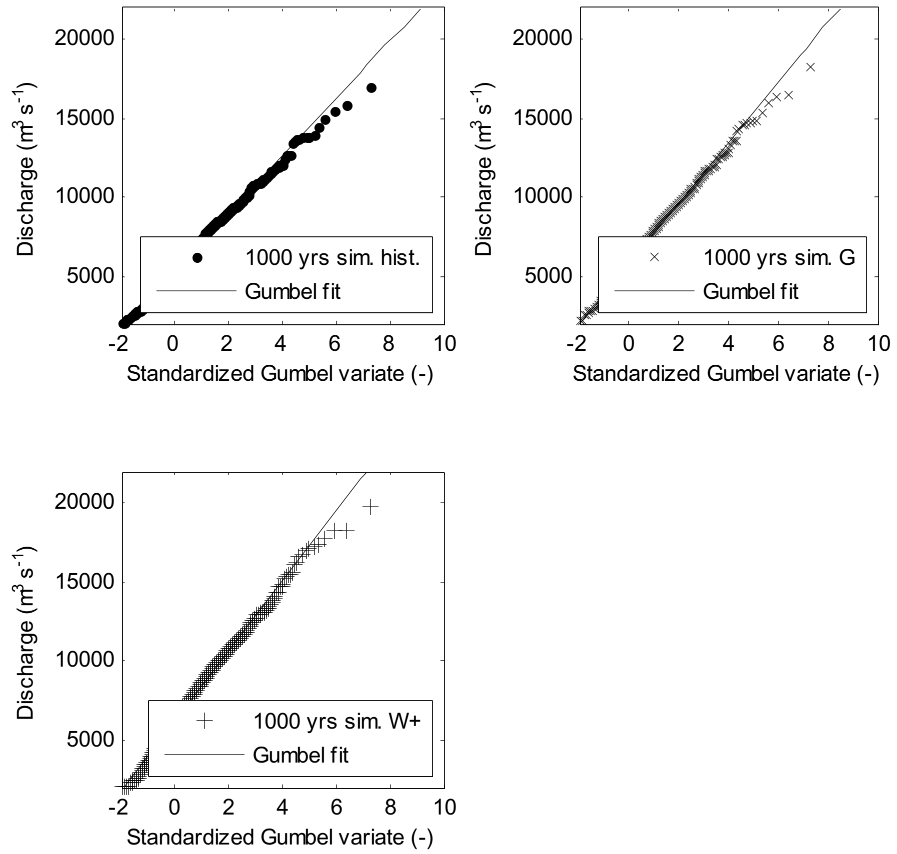

Figure 2. Gumbel distribution and Gumbel fit of yearly maximum of 1,000 years of simulated discharge at Lobith, based on historical meteorological data for 1961-1995 and climate scenario G and W+.

Table 2. Extreme values analysis and Gumbel fit at Lobith

Return period (years)	Gumbel fit of yearly maximum of 1,000 years of simulated discharge, based on: Historical meteorological data	Climate scenario G	Climate scenario W+
100	13,776	14,588	16,447
500	16,692	17,672	20,036
1,000	17,946	18,997	21,580
1,250	18,349	19,424	22,076

DISCUSSION AND CONCLUSIONS

All climate runs using the KNMI'06 scenarios for the year 2050 as input data, show an increase in mean winter discharges and a decrease in mean summer discharges for the Rhine basin. There is a wide range in these predicted changes, especially in the summer decrease, depending on the input scenario. At Lobith, the maximum increase in mean winter discharge is 16%, and the maximum summer decrease is 42%, both the result of the most extreme climate change scenario W+. The moderate climate scenario G shows 8% increase in winter discharge and minor changes in summer values at Lobith. The extreme value analysis of the 1,000-year runs by FEWS Extreme Discharges, resulted in the W+ scenario showing the most extreme increase in extreme values (20%) when compared to the G scenario (5.8%).

It can be concluded that the expected changes in temperature and precipitation due to climate change, very likely will result in changes in the discharge regime in the Rhine basin. By looking at relative changes in discharge instead of absolute changes for both scenarios, many errors and model uncertainties can be neglected. Even though the trend of expected changes is displayed here, these results must be considered and treated as preliminary results. It should be noted that the transformation of climate forcing data according to climate scenarios is done in a simplified matter. At this moment, it is not clear how well these scenario datasets of precipitation and temperature for the Rhine basin, represent the future climate scenarios, as presented by the KNMI for the Netherlands. Research is ongoing, which will produce more statistically adapted and geographically varied, meteorological input datasets for the Rhine basin.

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Floods evolution in a Climate Change framework: a Mediterranean analysis

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Keywords: flash-floods, heavy rain, Barcelona, Catalonia

ABSTRACT

Floods are the most common natural hazard in the Mediterranean region and they produce the greatest economic losses in that region. The types of rain responsible of the majority floods in the Mediterranean area are those corresponding to high intensity occurring during a short period of time over little steep basins, usually known as flash-floods. However, floods are a complex hydrometeorological hazard, but hydrology and meteorology processes play a major role. Heavy rains, long rainy periods or snowmelt are necessary but not sufficient to be responsible of their occurrence. Other conditions such as previous precipitation, terrain and surface run-off characteristics are also important. The natural phenomenon also interacts with human activities: land uses and their evolution, civil and hydraulic infrastructures can have very variable effects on the natural pattern for floods response. As a consequence, the relationship between climate change and floods is not evident. Besides the rainfall evolution, changes in other factors are needed to be considered. In this contribution an analysis of the floods and rainfall evolution in the Eastern Spain has been made. Information from other South European countries has been also taken into account. The analysis considers the evolution of different types of floods since the 14th century, the main meteorological factors responsible and any possible change. In addition, daily and monthly rainfall data from Barcelona city since 1780 are also used. The Montecarlo test has been applied in order to know the significance of any trend. Floods and rainfall evolution have been compared taking into account the changes produced in the land uses.

INTRODUCTION

Catalonia (North-eastern Iberian Peninsula, **figure 1**) is currently affected by natural disasters such as water shortage periods, wild fires, wind temporal, snow avalanches and floods among others. In fact, floods are the natural hazard with highest impact on society, and it is generating the major economical losses, reaching the total amount of 1,326 M€ for the period 1987-2002 (CSS, 2004). A study regarding all newspaper headlines appeared in the major Catalan newspapers since 1982, shows that floods get the 42% of news headlines related to meteorological risks (Llasat-Botija et al., in press). In **figure 2,** it could be seen more detailed information about headline percentages of the different meteorological hazards.

The number of floods evolution, as well as any relation with a climate change scenario has been always an issue with high consideration in the scientific purposes. However it presents many troubles, thus data used to get such information contains bias, gaps and inhomogeneities. Despite being a difficult aim, there are several ways which could provide us valuable information about floods evolution in time.

Figure 1. Catalonia is located in western Mediterranean, in the north-east corner of the Iberian Peninsula

One of them is the use of proxy data. Getting collateral or indirect information linked to floods in the past, is an appropriate way for collecting natural hazard events. There are many examples of extracting information about a certain meteorological variable by means of proxy data (i.e. Luterbacher et al., 2002). Other way, is using rainfall data, measured with modern meteorological stations. That way, despite being a suitable one, do not allow to go too far in the past.

The climatic future scenarios take here an outstanding role, thus Mediterranean area is being considered one of the most affected regions in the future. Recent downscaled scenarios for the Iberian Peninsula (INM, 2007) have recently suggest an increasing probability of flood occurrence in the Iberian Mediterranean region, thus autumn precipitation in the future could go up, and consequently the number of floods. Another problem is the growing vulnerability and the consequent increase of economic losses as points the study of CSS (2004), which projects a total amount of 3.605 M€ in Catalonia for the period 2004-2033. This amount means an increase of 45% in annual losses.

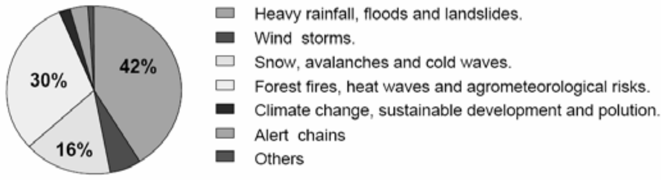


Figure 2. Percentages of the different natural hazards appeared in the mass media in the last 25 years (Llasat-Botija et al., in press).

Regarding climatological features, the Catalan coast is a clear example of a Mediterranean climate, with dry and hot summers, and two rainy seasons; autumn and spring. This fact implies that rainy seasons are where heavy rainfall phenomena have higher probability of occurrence. On the other hand, it is well known that autumn is the season where the major number of flood cases happens (Barnolas and Llasat, 2007).

Other issue to take in consideration is the fact that floods in the studied area are usually linked to extremely intense rains. Moreover, such rainfalls are often recorded over little basins of typical non permanent Mediterranean rivers. These basins has strong slopes, thus mountain ranges are close to the sea. These facts explain the most common floods are the so-called flash floods. That sort of floods is the most dangerous type. They become suddenly and with great power and velocity and it is difficult to do an accurate prediction and warnings. With this information, the rainfall study has to be focused on small time aggregation rainfall values. Monthly values or other time aggregation values are not suitable to compare rainfall values and flood evolution in Catalonia.

METHODS

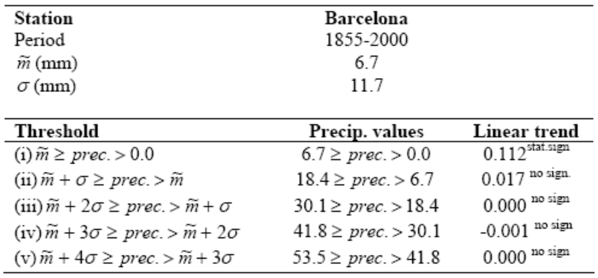
Evaluation of flood behaviour: flood chronologies

Flood chronologies are generally lists of flooding events in a particular locality. The floods are identified from documentary sources, such as chapter books of resolutions from city councils, public works files, technical reports, religious ceremonies, memoirs, diaries, chronicles, newspapers… These sources contains information on damages and losses, details on the behaviour of the rising water (duration, magnitude, indirect measurements), further details about the precipitation episode that gave rise to it, and crop productivity among others. The floods can be classified following a common criterion used for identifying floods occurred in the 14th-19th centuries and the 20th-21st centuries (Llasat et al., 2005): extraordinary floods (floods with minor damages) and catastrophic ones (floods with severe damages and destructions).

An exhaustive search for flood occurrence in Catalonia (Barriendos and Pomés, 1993; Barriendos and Martín-Vide, 1998; Barnolas and Llasat, 2007) and Barcelona County (Barrera et al., 2006) since the 14th century has been done for the last 20 years. Thanks to all those works and the SPHERE and RAMSHES projects, twelve main flood chronologies have been developed and updated in Catalonia. These chronologies are used for constructing a regional series of flood indices, taking into account the prior work of Barriendos et al. (1998). The indices are defined as the average of the normalised annual values of extraordinary and catastrophic floods. This series is tested to search for trends using the Montecarlo technique (Livezey and Chen, 1983). The flood indices for Barcelona County have also been considered (extraordinary, catastrophic and flash-flood ones).

Evaluation of precipitation behaviour; daily rainfall trends

The rainfall data used for developing the rainfall-flood comparison are from Barcelona station, for the period 1854-2005. This was the only way to have a comparable period large enough in order to compare rainfall characteristics and floods evolution. But, several considerations have been taken into account with the rainfall data. A study focus on extreme daily rainfall events would be needed. Therefore, annual maximum precipitation (AMP in future), and picks over threshold (POT in future), should be taken into account for a correct rainfall assessment. POT values are calculated considering statistical parameters such as mean and sample standard deviation. The different POT (**table 1**), will be got by adding standard deviations values to a prefixed rainfall value (the mean). The higher the rainfall threshold, the more is the relation with possible flood occurrence. Linear trends are calculated in order to test any possible tendency. In addition, the result statistical significance is corroborated using a Montercarlo technique at 95% of confidence level.



Station	Barcelona
Period	1855-2000
$\tilde{m}$ (mm)	6.7
σ (mm)	11.7

Threshold	Precip. values	Linear trend
(i) $\tilde{m} \geq prec. > 0.0$	$6.7 \geq prec. > 0.0$	$0.112^{\text{stat.sign}}$
(ii) $\tilde{m} + \sigma \geq prec. > \tilde{m}$	$18.4 \geq prec. > 6.7$	$0.017^{\text{no sign.}}$
(iii) $\tilde{m} + 2\sigma \geq prec. > \tilde{m} + \sigma$	$30.1 \geq prec. > 18.4$	$0.000^{\text{no sign}}$
(iv) $\tilde{m} + 3\sigma \geq prec. > \tilde{m} + 2\sigma$	$41.8 \geq prec. > 30.1$	$-0.001^{\text{no sign}}$
(v) $\tilde{m} + 4\sigma \geq prec. > \tilde{m} + 3\sigma$	$53.5 \geq prec. > 41.8$	$0.000^{\text{no sign}}$

Table 1. Selected rainfall thresholds for Barcelona station. Linear trends have units of events/year.

RESULTS

Figure 4 shows the evolution of flood indices for Catalonia from 1301 to 2005. The number of extraordinary floods has a significant increase. This feature is also observed in the evolution of flash-floods in Barcelona County (**figure 5**). However, no significant trend is found in the catastrophic floods evolution but three main periods with higher occurrence of events are clearly identified: 1570-1610, 1760-1800 and 1840-1870, approximately. All of them are corresponding to past climatic oscillations which implied a great variability (Barriendos et al, 1998).

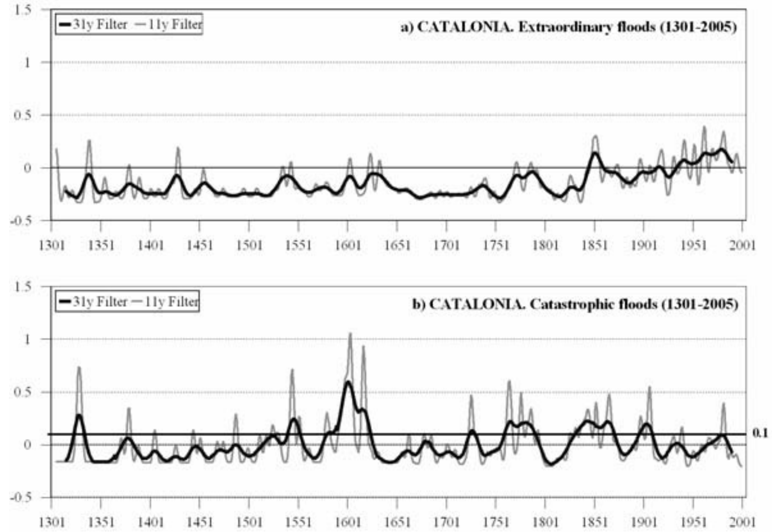


Figure 4. Evolution of extraordinary (a) and catastrophic (b) floods indices in Catalonia from 1301-2005.

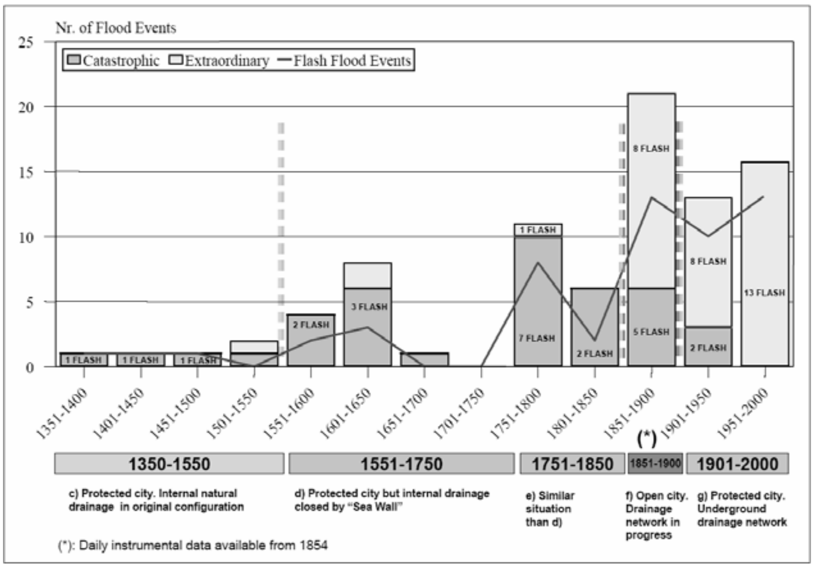


Figure 5. 50-year period flood distribution in Barcelona county from AD 1351 to 2000 (Barrera et al., 2006).

Considering the rainfall study (**figure 6**), no significant trend has been found regarding the daily extreme precipitation evolution for the largest available series of Western Mediterranean (Barcelona, 1854-2005). Statistical significance of AMP trend has been also tested with Spearman and Mann-Kendall non-parametric tests, all of them providing no statistical significance for the obtained trends. In addition, no significant trend could be detected in the evolution of several daily rainfall thresholds (POT, **table 1**). Although, the lowest POT shows a significant statistical trend (0.11 events per year), this POT value is not associated to flood occurrence. This time, statistical significance has been tested by means of Montecarlo technique at 95% of confidence level.

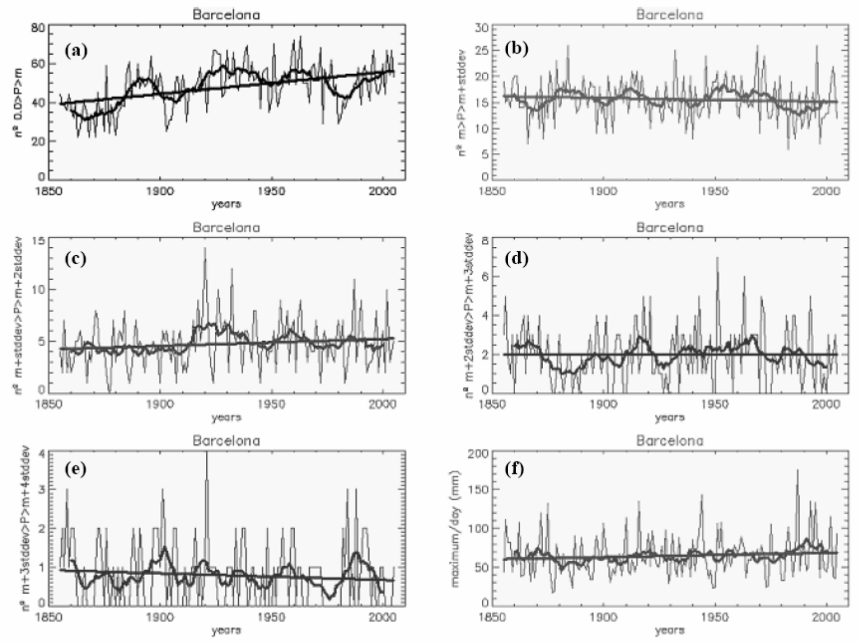


Figure 6. Picks over threshold (POT) for Barcelona daily precipitations series (a)-(e) and annual maximum precipitation (f) from 1854 to 2005.

DISCUSSION AND CONCLUSIONS

Among the obtained results, some clear conclusions could be inferred. The first one is that the number of extraordinary floods is going up, especially in the last years. In fact, statistically significant trend has been found. On the other side, no clear tendency is observed in catastrophic floods. Nevertheless, some periods with high flood activity have been identified.

Taking in consideration daily rainfall tendencies, no trends have been found in the performed daily rainfall studies, neither in the POT nor in the AMP evolution. This is in contrast to other studies performed in different Mediterranean stations located in the Central Mediterranean basin (Alpert et al., 2002; Altava-Ortiz, 2006), which point respectively to an increase number of heavy rainfall events within a reduction of annual rainfall values context. Unfortunately, it is missing floods chronologies in such places. It would be very useful in order to perform a complete comparison between rain and floods evolution for whole Mediterranean region.

But, extraordinary floods trends in Catalonia and particularly in Barcelona County, shows an increase tendency. This fact has to be explained in terms of vulnerability variation and an impact increase over the region. So that, floods could become more frequent because of the high increase of urbanisation development during the last 150 year, especially over littoral places, which are plenty of little and steep non-permanent river basins.

Acknowledgements

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Drought and spatialization of the precipitations in the North-West of Algeria

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Keywords: pluviometric regime, dryness typology, spatialization of the precipitations, North-West of Algeria

ABSTRACT

To detect the possible changes in the pluviometric regime, we use the statistical tests of Pettit, Lee Héghinian and the segmentation of Hubert on ten long-term stations. For the majority of stations, a rupture (reduction in annual pluviometry) appears between 1970 and 1980. This fall caused a depth of runoff reduction from 61% to 71% on an annual scale in the extreme west, for the remainder of the studied area, the reduction is about 40 %.

In order to establish a typology of the dryness, we retained the station of Oran (west of Algeria) which has long series and we applied a simple method expressing the pluviometric deficit as an annual average percentage. The analysis of this series (1877/78-1997/98) reveals that the most severe period of the deficit spread over a dozen years, 1977/78 to 1988/89 with a light surplus during 1979/80 and a maximum deficit (-213,6 mm) recorded during 1922/23. Over the studied period (120 years), we record 62 deficit years, including 21 affected by a moderate dryness and 11 can be regarded as dry (according to the criterion defined above). The deficit recorded during 1922/23 (-213,6 mm) has return period of 244 years, the deficits of 1944/45 (- 212.3 mm) and 1982/83 (-208.9 mm) corresponding to recurrence times of 81 years and 44 years respectively.

Three elements structure the annual fluctuations of the rains: the latitude, the longitude and the altitude of the studied zone. By the established chart, we tried to show the interannual variability of the rains. The interannual variability of the rains increases when we approach to the arid areas. That was checked. We observe the Increase in variability with an increase in longitude and latitude reduction. Altitude attenuates this increase.

INTRODUCTION

The study of annual variability of precipitations is important for the projects of agricultural and hydrolic development. It is also of a considerable contribution in the study of the climatic changes. To detect possible changes in the pluviometric regime, we used a certain number of statistical tests on ten precipitations stations having a length chronological series. In order to establish the dryness's typology, we retained the station of Oran. Wich possesses a long series and applied a simple method expressing the pluviometric deficit as a percentage of annual average. The spatialization of the precipitations irregularities was approached by the coefficient of variation of the available chronological series (218 pluviometric stations). This coefficient allows the comparison between the stations.

Geographical situation

The studied zone extends on 89420 km^2 approximately. It is located between 2°10' 10 western `' and 3°10' 11 " East of longitude and between 34°18' 54 " and 36°48' 12 " of Northern latitude (fig. 1). The studied area extends on 250 km from the South to the North and 500 km approximately from the West to the East.

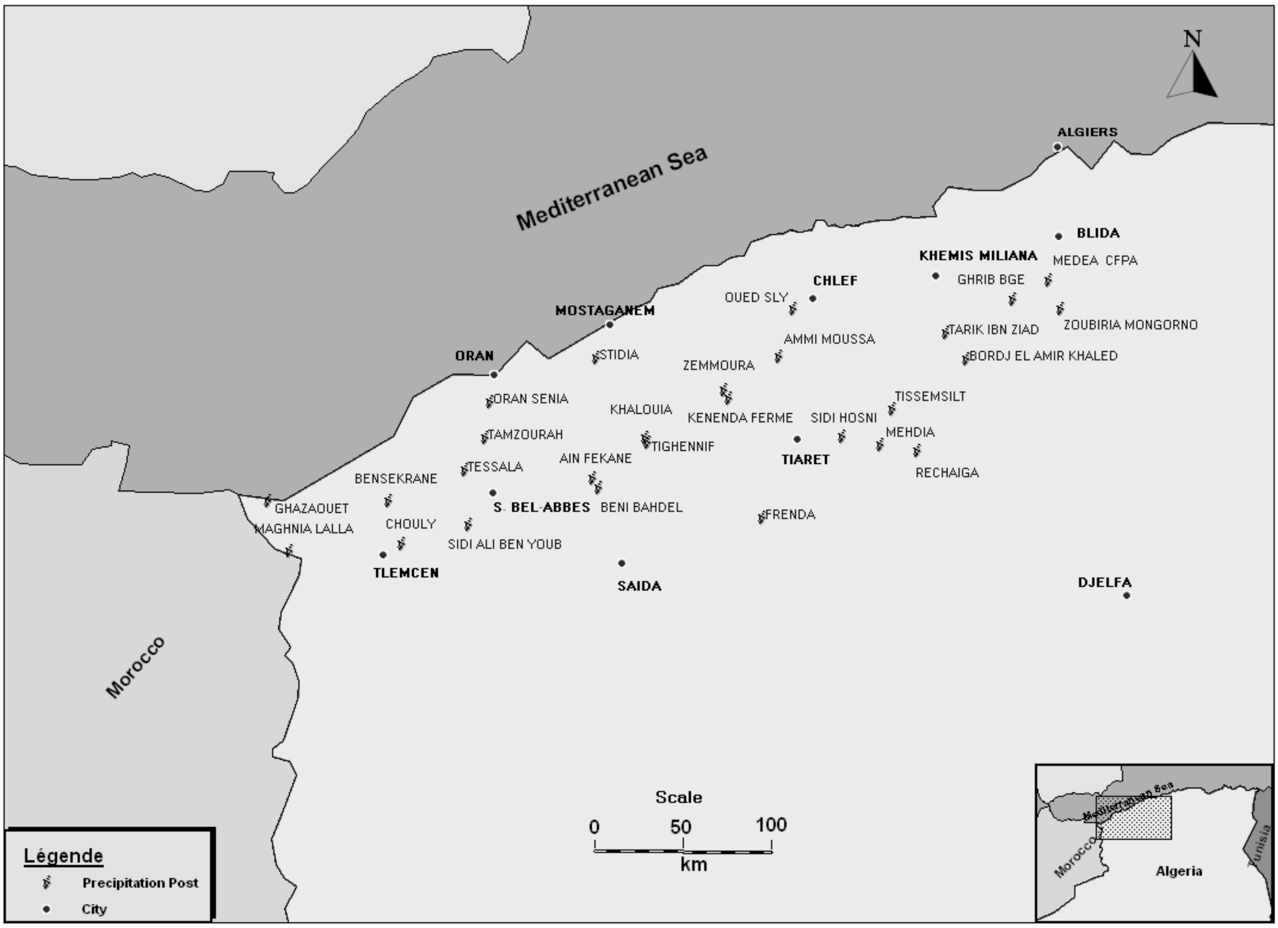

Fig. 1. Precipitation post studied

DATA

The spatial and temporal representativity of the precipitation station have an important influence on the quality of the pluviometric study. We possess 28 station records (Fig n°1 and Tab n°1) at random distribute in studied area for detection of breaks in the time series and 218 stations with 30 years of observation (1968-1998) to study the spatial variability. The data series are collected from National Agency of Hydraulic Resources and National Office of Meteorology. The precipitation station selected has a sufficient series to accomplish this study.

DETECTION OF RUPTURE

In order to detect the possible changes in the pluviometric regime, we used the statistical tests of Pettit, statistics of Lee Héghinian and the segmentation of Hubert (Lubes and Al, 1997; Hubert and Al, 1989 and Hubert and Al, 1993). These tests were applied to the chronological series of the annual rainfall of the following stations: Ain Fekane, Ghazaouet, Khalouia, Maghnia, Tighenif, Zemmoura, Tamazourah, Tessala, Bensekrane, Stidia, Sid Ali Ben Youb and Oran. The tests reveal that climatic variability in this region as a whole (reduction in annual rainfall total) appears between 1970 and 1980 with a variable threshold of significance from one station to another. These results confirm the appearance of a pluviometric deficit since 1970, and the continuation of this phenomenon during the decade 80-90. This phenomenon still persists currently and generates a serious economic and social problems, considering the increasing pressure which is exerted on the water resource (drinking water supply, irrigation...), Meddi and Humbert, 2000.

Tab. n° 1. The precipitations of studied station and their characteristics

Stations	Lambert Coordinate X (km)	Lambert Coordinate Y (km)	Altitude Z (m)	Observation length
Stidia	256.25	284.75	41	1900-1998
Ain Fekane	254.9	218.37	456	1905-1998
Ghazaouet	75.58	203.77	76	1930-1998
Khalouia	284.01	240.69	550	1929-1998
Maghnia	88.3	176.4	395	1930-1998
Tighenif	195.45	239.90	189	1922-1998
Zemmoura	327.4	267.3	320	1930-1998
Tammazourah	195.45	239.90	189	1913-1998
Tessala	184.5	222.05	577	1914-1998
Bensekrane	142.45	204.65	247	1923-1998
Sid Ali Ben Youb	186.55	192.2	635	1913-1998
Oran	197.9	259.79	90	1874-1998
Oued Sly	365.20	312.70	95	1925 – 1998
Sidi Hosni	392.95	242.05	790	1930 – 1998
Frenda	348.60	197	990	1926 - 1998
Mehdia	413,90	237,35	918	1930-1998
Rechaiga	434,50	234,50	830	1915-1998
Zoubiria Mougorno	513,50	312,60	932	1930-1998
Ghrib bge.	487,25	318,40	460	1930-1998
Medea CFPA	506,80	329,15	900	1930-1998
Tarik Ibn Ziad	450,15	299,50	660	1951-1998
Borj El Amir Khaled	461,10	285,30	370	1951-1998
Ammi Moussa	357,40	286,15	140	1926-1998
Kenenda ferme	330,15	262,60	590	1926-1998
Beni Bahdel	254,30	217,20	666	1941-1998
Chouly	149,65	181,00	700	1941-1998

TYPOLOGY OF THE DRYNESSES

In order to establish the dryness's typology, we retained the station of Oran wich possesses long series and applied a simple method expressing the pluviometric deficit expressed as a percentage of annual rainfall (Hadjri, 1996). The considered year presents a moderate dryness if the deficit varies between 20 and 40 % of the annual precipitation; it is dry if the deficit varies between 40 and 60 %; it is very dry if the deficit varies between 60 and 80 %; it is hyper dry if the deficit of annual rainfall exceeds 80 %.

The analysis of the data series of the Oran station (1877/78-1997/98) reveals that the most severe period of the deficit of annual rainfall ispreads out over a dozen years, 1977/78 to 1988/89 with a light surplus during the year 1979/80 and a maximum deficit (-213,6 mm) recorded during 1922/23. Over the studied period (120 years), we record 62 deficits years, including 21 having been affected by a moderate dryness and 11 years being able to be regarded as dry (according to the criterion defined above). The deficit recorded during 1922/23 (-213,6 mm) has a return period equal to 244 years, the deficits recorded during 1944/45 (- 212.3 mm) and 1982/83 (-208.9 mm) has respectively 81 years and 44 years as return period. Always for the same station but for the reference period (1950/51-1987/88), the maximum deficit is -203.5 mm, recorded during 1982/83. On the totality of the series, 25 years showing deficit (52 %), 10 years are regarded as moderately dry and 3 years like dry. The year

(82/83) is characterized by return period of 98 years; it is followed by the year 1981/82 which has 33 years as return period.

Tab. n° 1. Tests statistiques de rupture des séries pluviométriques de quelques stations

Stations	Test ofPettit	Lee Héghinian	segmentation de Hubert	Mean (mm) before Break	Mean (mm) after Break	Difference en %
Ain Fekane	1974	1974	1974	704.5	421.4	22
Ghazaouet	1974	1974	1974	388.6	301.7	22.4
Khalouia	1980	1980	1980	486.9	341.7	29.8
Maghnia	1980	1980	1980	465.5	277.3	40.4
Tighenif	1980	1980	1980	512.8	282.4	44.9
Zemmoura	1973	1973	1973	483.7	347.7	28.1
Tamazourah	1973	1973	1973	463.1	335.1	27.7
Tessala	1971	1974	1974	526.6	314.5	40.3
Bensekrane	1964	1964	1964	518.6	386.2	25.5
Stidia	-	1980	-	406.6	341.7	16
Sid A B. Youb	1975	-	-	402.2	313.6	26.2
Oran	-	1976	1976	392.9	318.9	18.8
Oued Sly	1979	1980	1980	384.1	251.3	34.6
Sidi Hosni	1976	1977	1976	177.9	92.8	47.9
Frenda	1978	1980	1980	476.3	357.9	24.8
Mehdia	1976	1979	1970	415.7	314.9	24.2
Rechaiga	1976	1977	1977	312.3	196	37.3
Zoubiria Mougorno	1979	1979	1972	554.1	475.8	14.2
Ghrib bge.	1975	1975	1975	545.4	436	20.1
Medea CFPA	1975	1975	1975	840.5	673.4	20
Tarik Ibn Ziad	1978	1973	1973	555.7	370.2	33.4
Borj El Amir Khaled	1978	1978	1966	412.5	306.5	25.7
Ammi Moussa	1977	1979	1979	416.4	318.5	23.5
Kenenda ferme	1978	1978	1978	478.6	269.7	43.6
Beni Bahdel	1974	1974	1974	537.8	432.5	19.6
Chouly	1980	1975	1975			

SPACE ANALYSIS

The spatialization of the irregularities of precipitations can be approached by the coefficient of variation of the chronological series of 218 precipitations stations calculated over 30 years (1968/69-1997/98). This coefficient allows the comparison between stations. The increase in variability (fig. 2) goes hand in hand with an increase in longitude and the latitude reduction. The altitude attenuates this increase.

CHELLIF BASIN (01) - 64 precipitation stations

The Chellif basin is characterized by an annual average rainfall (over 30 years) which varies from 148 mm to 746 mm from a station to another. The coefficient of variation of the annual averages is 30 %, which shows a moderate variability of precipitations. The space variability (from one station to another) varies from 29 % to 51 %.

COTIERS OF THE ALGEROIS BASIN (02) - 14 precipitation stations

The coastal Algiers Basin is characterized by a very broken relief with peak which reaches 1415 m (Djebel Dahra) in the Western part of the basin and 2308 m (Djebel Djurdjura, Kabylie) in the East of catchments. These mountains chains and the Blidieen Atlas which succeed to the Mitidja plain cause the progressive impoverishment in steam. Those have a great influence on the space variations of precipitation (A. HALIMI, 1980). The annual average precipitation (30 years) varies from 532 mm to 950 mm. This variability is generated by the effect of altitude, the distance from the Mediterranean sea and the form of the relief (exposure to the winds). The space variability of pluviometry from one year to another varies from 18 % to 47 %. 70 % of the stations have a space variation (from one station to another) near to the average (25 %) and 30 % have a space variation more than 30 %.

COASTAL ORANIAN BASIN (04) - 22 precipitation stations

The coastal Oranian catchment has a less broken topography compared to the other basins. We find the plain of Oran. It is characterized by moderate altitude witch does not exceed 100 m. It is characterized by a weak pluviometry, from 302 mm recorded at the station of Marsa Ben Mhidi (extreme west) to 398 at Hammam Bouhadjar station. The space variability, from one year to another and from one station to another, is moderate (from 10 % to 36 %). These small percentages are due to the moderate relief and to the weak rains recorded in this basin.

MACTA BASIN (11) 91 precipitation stations

The catchment area of Macta (Western of Algeria) is limited in the North by Beni Chougranne mountain, Tessala mountain and the plain of Mohamadia, in the South by Saida and Daya mountain (1356 m) in the Western South by Tlemcen mountain. The Annual pluviometry is weak, it varies from 206 mm recorded in the southern (Bouhnifia and Sfisef stations) to 380 mm on the mounts of Saida (1201 m) and on the North-western basin (Sidi Belabess mountain and peak of Tessala). The space variation is moderate; it varies from 20 % to 43 % with an average (30 years) of 25 %.

TAFNA BASIN (16) – 20 precipitation stations

In the Tafna basin situated in the extreme west of Algeria (boundary of Morocco) limited: in the North-West by Terara mountain (1021 m), and in the North-East by Tessala mountain. This basin is composed in its South-East part by Tlemcen mountain (from 1576m to 1843m), and in his Northern part, by plateau (from 200 to 500 m of altitude). Annual rain varies from 260 mm on the level of the plain of Tlemcen to 650 mm on the peaks of Tlemcen Mountain. Space variability oscillates between 21 % and 57 % with an average (on 30 years) of 30 %. More than 90 % of the years of observation give coefficients of variation (space) lower than 40 %, which confers that in this basin the space variability is moderate.

CONCLUSION

The study of the pluviometric regime in the North West of Algeria reveals a climatic variability at the beginning of the seventies (reduction of pluviometry) for the quasitotality of the studied stations. The annual variability of the precipitations increases when we approach the arid areas. The increase in the variability follows the increase in longitude and the reduction in the latitude. The altitude attenuates this increase.

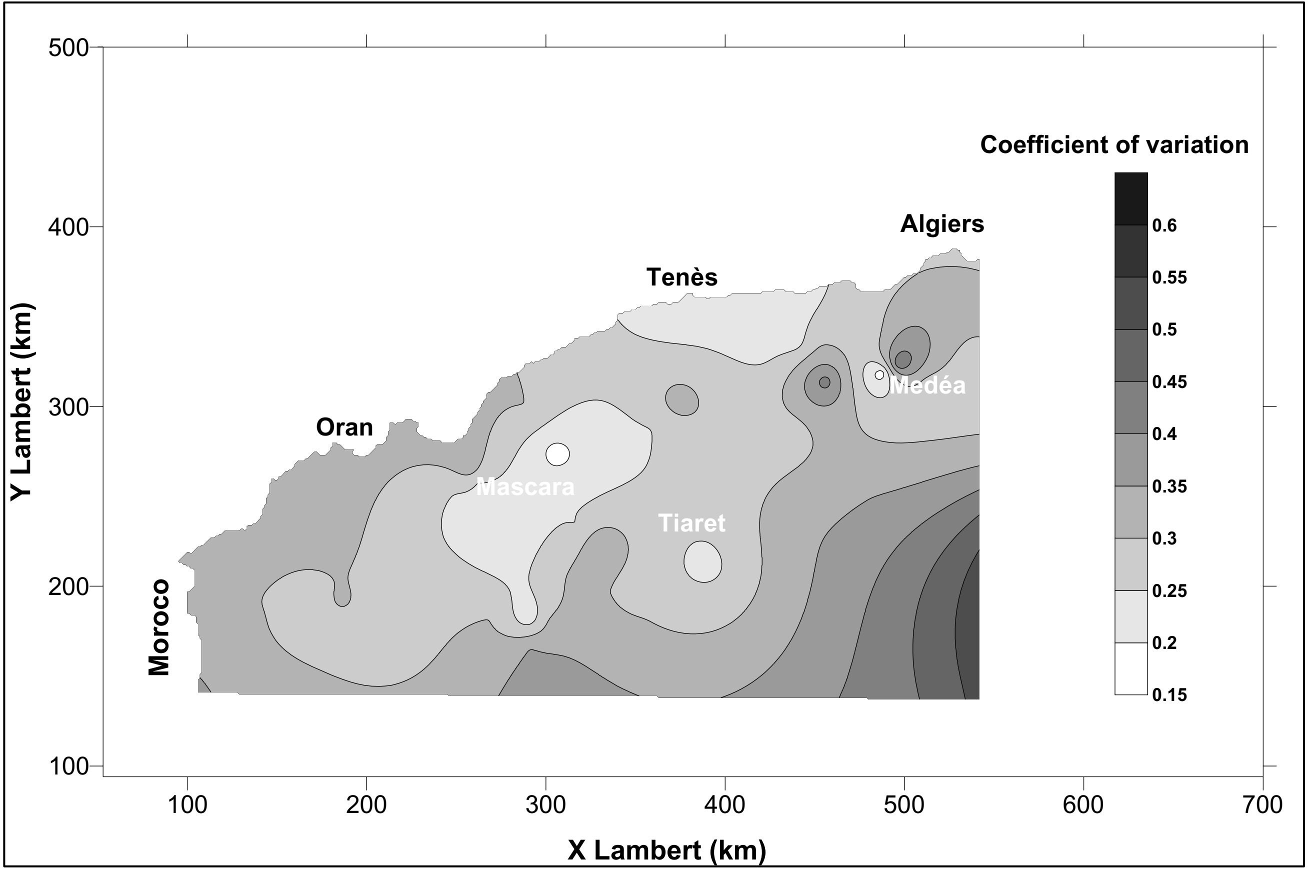

Figure 2. Coefficient of variation of annual precipitation

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Study of the daily pluviometry in the North of Algeria

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Keywords: Daily pluviometry, number of rainy days, statistics tests, rupture, North of Algeria

ABSTRACT

In Algeria, the rains are characterized by a very strong interannual and seasonal irregularity. This variability leads to extremely severe low water and strong flood that means considerable human and material damage caused by the generated floods.

The appearance of the daily maximum rains varies considerably from one month to another. For the West and Center stations, the rains are concentrated in the winter's months then the frequency of appearance of these rains decrease notably in the spring's months. For the stations of the east of Algeria, the concentration appears either in spring (February), or in winter but with an important frequency of appearance over several months (October, November, December).

Statistics tests applied to the daily maximum pluviometry series and the number of raining day. We retain that in the East of Algeria, no significant rupture could be detected. For the rest of the Algerian territory and for the used tests, the rupture occurred during the decade 1970-1980 and during this period the decrease of daily precipitations became a reality.

INTRODUCTION

The multiplication and the aggravation of the deficiency of water are universally taking a dimension of first order. In Algeria, the deficit of this blue gold became worrying confirming the various expertises on the basis of different assumption and using of methodology which concluded that our country will be in the few next years confronted to this quasi-endemic shortage. During these last decades, important pluviometric deficits are recorded in the West of Algerian. However in the East, it seems that the effects of dryness are also felt. Through this acknowledgement, it is pressing to identify the various modifications of maximum daily precipitations regime.

DATA

The table n°1 represents the 14 stations records retained for this study: localization, altitude and duration of measurement. The distribution and the density of the stations allow a study of a regional scale of daily precipitations: These stations have observations with a long-term but it appears insufficient to determine the local and regional nuances of daily rainfall, it is necessary to mention the discontinuity and gaps in the chronological series of observation. The work consisted in filling the gaps of the series of measurements.

STATISTIC ADJUSTEMENT (GUMBEL LAW)

For the study of the extreme rains, we interested only on the heavy values of precipitations. We generally adjust the law of Gumbel to those values (fig.1). From this theoretical adjusted law, we will be able to estimate the value of an unspecified event for a given probability. Generally, we interested on the very small probabilities concerning the extreme events. But, prudence requires that we do not look for the value of an event in which the probability of appearance corresponds to the period of return witch is higher or represent a triple of length of the sample. While basing on these criteria, we listed the extreme values relating to the annual maximum daily rainfall. The results are represented in table n°2.

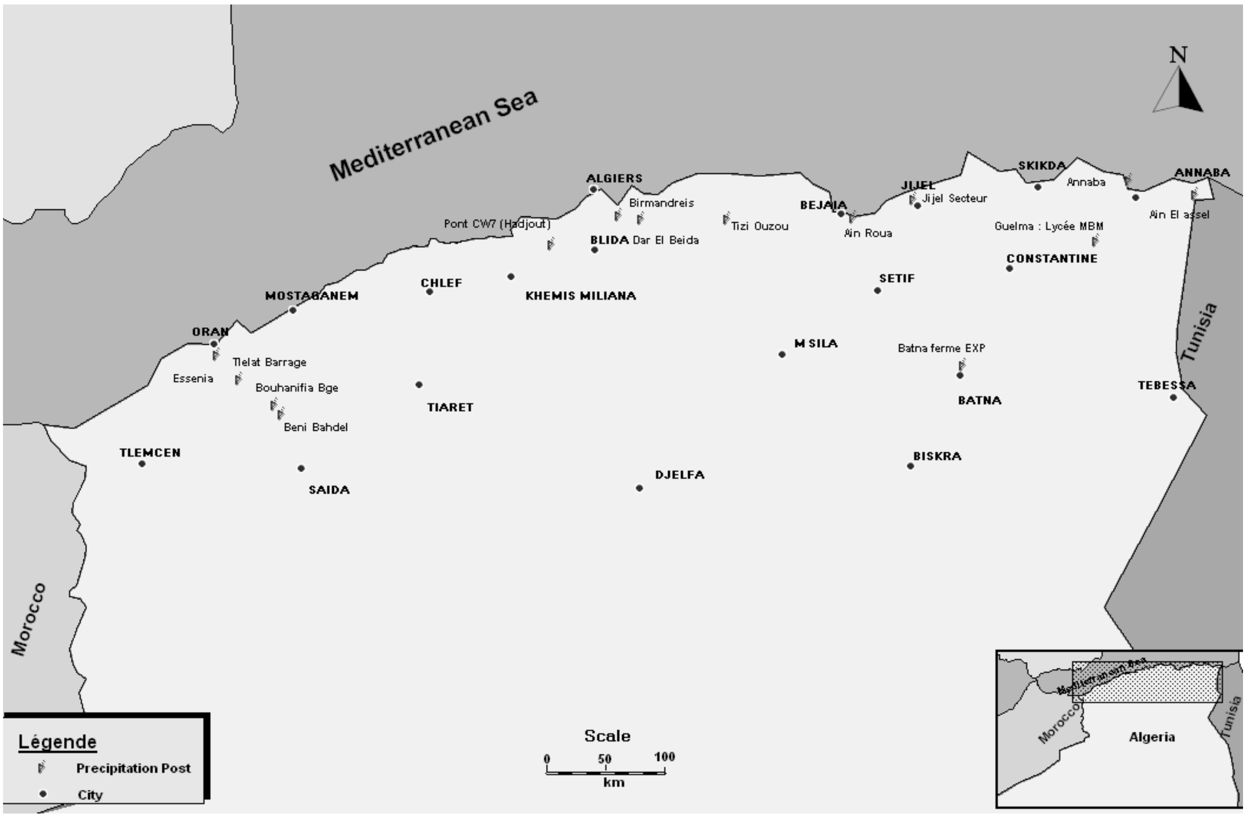

Figure 1. Situation of studied precipitation post

Table 1: list of used stations

Stations	Lambert Coordinates		Altitude	Observation Period
	X (m)	Y(m)	Z (m)	
Pont CW7 (Hadjout)	475,85	358,85	59,00	1972-2003
Tizi Ouzou ANRH	620,90	380,25	195,00	1984-2003
Birmandreis ANRH	531,10	382,80	140,00	1951-2003
Ain El Assel	1005,65	400,05	35,00	1967-2003
Guelma: lycée MBM	924,10	361,40	280,00	1972-2003
Batna ferme EXP	814,70	257,35	1040,00	1929-2003
Ain Roua	722,90	399,95	1100,00	1969-2003
Jijel secteur	774,10	396,15	5,00	1967-2003
Tlelat	219,80	245,75	280,00	1940-2000
Essenia	200,80	266,15	90,00	1927-1998
Beni Bahdel	115,00	164,60	666,00	1941-2000
Bouhanifia Bge	248,15	225,05	306,00	1941-2000
Annaba	951,10	411,35	80,00	1945-1998
Dar El Beida	549.72	380.32	25	1936-1998

CONCENTRATION OF THE MAXIMUM DAILY RAINFALL AT THE MONTHLY SCALE

The frequencies of the appearance of these rains, per month and per station, were used to study their concentrations. The histograms (fig. n°2 and 3) show that the appearance of these rains varies considerably from one month to another. For the stations situated in the West and in the Center of Algeria, the maximum rainfall concentrate in the winter months then the frequency of the appearance of these rains declines notably in the spring's months. For the stations located at the East, the concentration appears either in spring (February), or in winter but with an important appearance frequency on several months (October, November and December).

Table 2. extreme values of the maximum daily rainfall.

Station	Observed value	Return period	Year
Annaba	1166	111	1983
Ain El Assel	142.7	197	1992
Batna	78.5	110	1967
Guelma	100	104	1999
Dar El Beida	1366	160	1972
030205	158.1	258	1984
020509	136	67.4	1972
Senia	1116	229	1971
Beni Bahdel	1699	78.5	1953

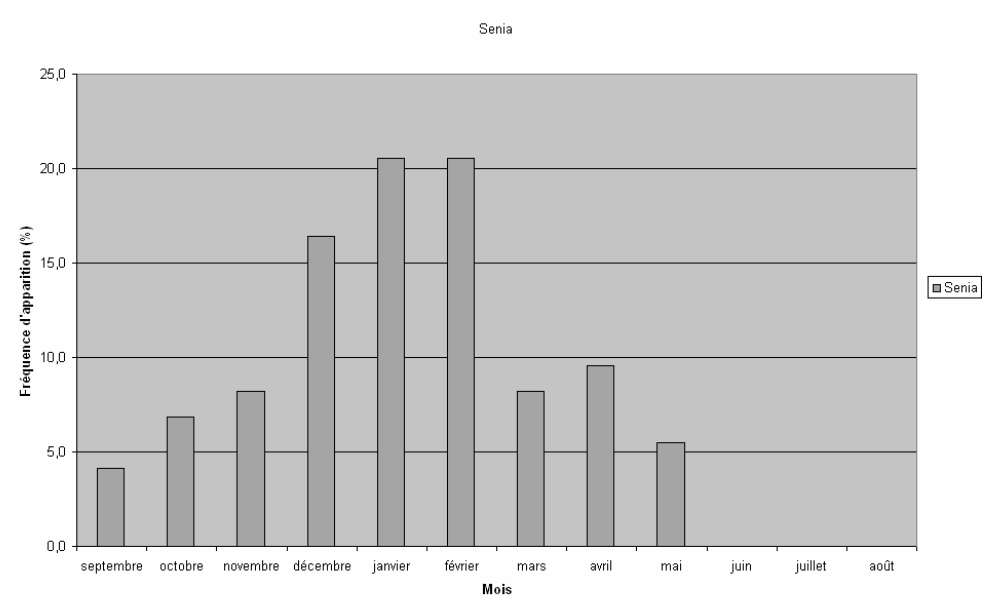

Figure 2. Appearance of the number of maximum daily rainfall per month for the Senia's station

STUDY OF THE EVOLUTION OF THE DAILY RAINS

Several studies treated the problems of the pluviometric regimes evolution in Algeria (Meddi and Talia, 2004; Matari and El Mahi, 2002). These studies showed the possible change in the evolution of precipitations on various scales at the middle of the Seventies. However, no precise date could be detected as being the beginning of the tendency. For that, we supposed 1974 (year of break for the west and Center of Algeria for annual rainfall) as year of rupture in the stationnarity of maximum daily precipitations.

By comparing the maximum daily precipitation (Pdmax, the number of days above several threshold rainfall values: 0.1 mm, 1 mm and 10 mm) before and after 1974 (fig. 4 and 5), we deduced that maximum daily precipitation, on the level of the west and the center, recorded a considerable fall. On the other hand, more in the east, these rains knew an increase in the number of daily rainfalls higher than a threshold and we noticed that the maximum daily rainfall passed from 1086 mm before 1974 to 1160 mm after 1974 at Annaba's station

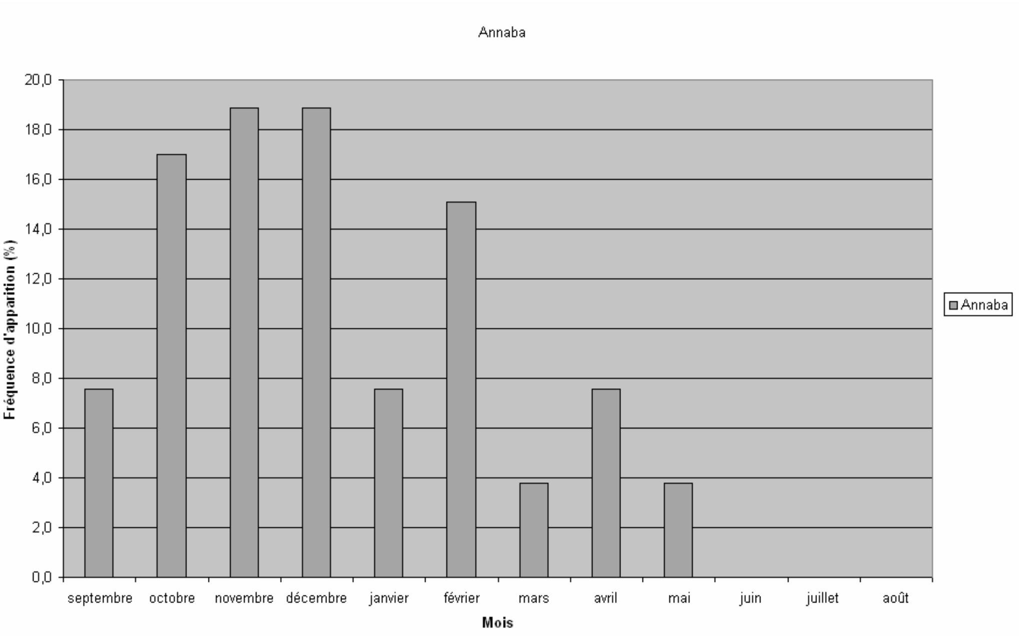

Figure 3. The appearance of the number of maximum daily rainfall per month for the Annaba's station

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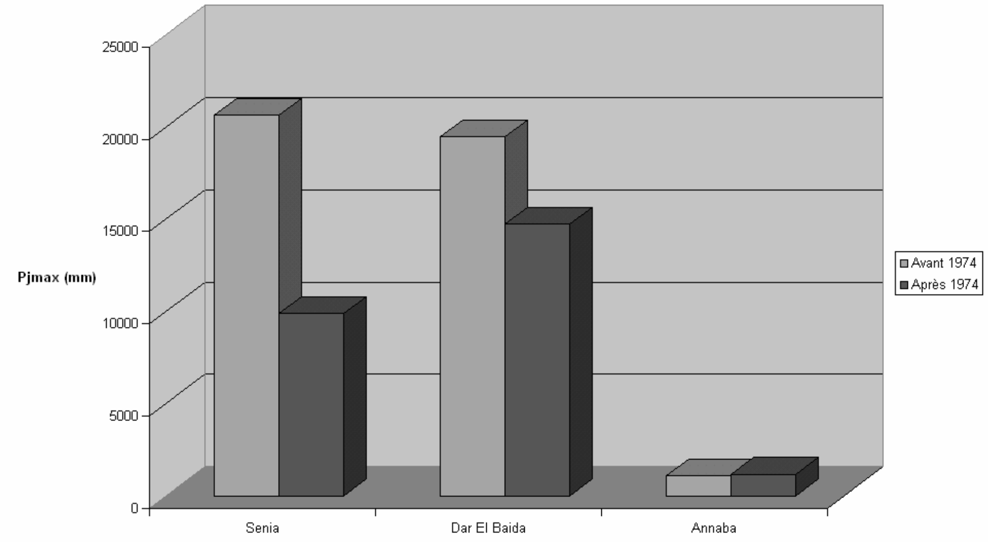

Figure 4. Comparison of Pdmax before and after 1974

The conclusions made above are based on a graphic analysis of the chronological series. To study the significativity of the date of break in the time series, several statistical tests were used. For that, we treated the totality of the information contained in the chronological series of the selected precipitations station. "Rupture or break in the time series" must be understood like a change in the law of probability of the chronological series at a given moment (Lubès and Al, 1994). We will point out their base here.

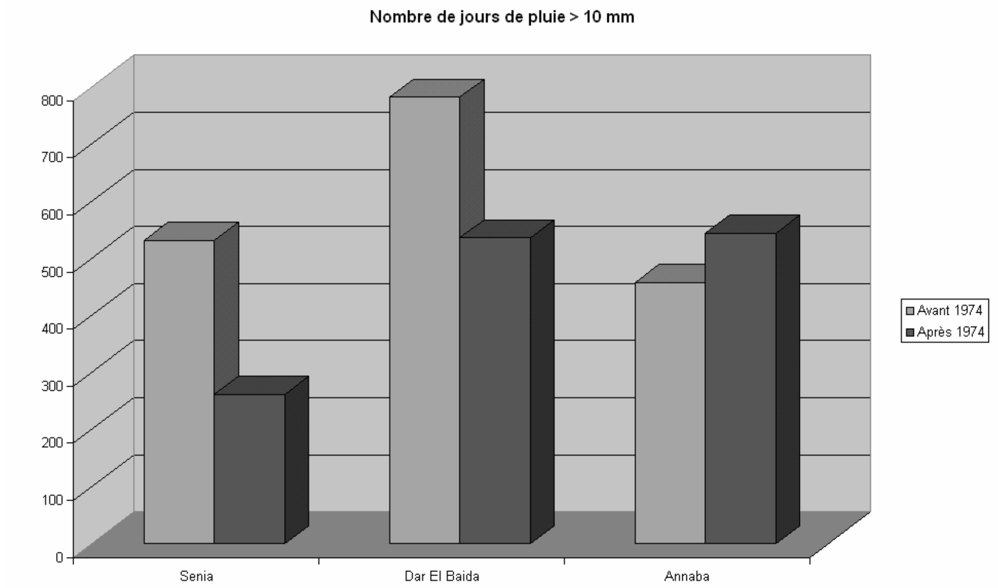

Figure 5. Comparison of the number of daily rainfall higher than 10 mm before and after 1974

The nonparametric test of Pettitt (Pettit A.N., 1979) examines the existence of a rupture at one unknown moment of the series starting from a formulation derived from that of Mann-Whitney (Dagnélie, 1970). This test is more particularly sensitive to a change of average and if the null assumption of homogeneity of the series is rejected, it proposes an estimate of the date of rupture. The statistics of Buishand (Buishand, 1982, 1984) are parametric supposing normality of the series, nonautocorrelation and constancy of the variance on both sides of the possible frangible joint. This test is powerful to detect a rupture in medium of series, but it does not provide an estimate of the frangible joint. The Bayesian defined by Lee Heghinian (1977) supposes the priori existence of a change of the mean somewhere in the series and yields at each time step an a posteriori probability of mean change. The nonparametric procedure of segmentation of hydrometeorological series (Hubert and Carbonnel, 1987) is adapted in the search of the multiple changes of average in the series. Its principle is "to cut out" the series in several segments so that the average calculated on any segment is significantly different from the average segments(s) neighbor by application of the test of Scheffé which proposes of contrast (Dagnélie, 1970).

Applied to each site, these tests, at least, give generally concordant results for the heterogeneity in the series, even if the estimates of the ruptures, on average, given by several tests differ sometimes from few years (Table 2).

From the founded results, we retained that in the East of Algeria, no significant rupture could be detected. Moreover, no rupture in the pluviometric series was found by a similar study in central of Tunisia with the same statistical tools (Kingumbi et al.; 2001).

For the rest of the Algerian territory and for the whole of the tests, the rupture occurred during the decade 1970-1980 so that's where the fall of daily precipitations became a reality. This rupture, in the direction of a reduction in the daily rains in the West and Centre of Algeria, gives to reflect for better managing of water resource.

CONCLUSION

Many interrogations can be posed as for the causes, to consequences, existence or not of a variability of pluviometry regime in Algeria. It is delicate to advance a general tendency even if the annual, seasonal, monthly and daily distribution of precipitations of these two last decades were particularly irregular from one year to another.

The studied area is characterized by a contrasted relief and a vast surface, Algeria offers a great diversity of climates which vary with the distance of the sea. This makes the interpretation delicate and generalization of the obtained results.

The study of detection of rupture made it possible to locate a modification of the pluviometric regime during the decade 1970-1980 for the majority of the studied pluviometric stations except, the zone located in the extreme East.

So, the change of the regime which Algeria knew these two last decades saved the East of Algeria. However, the climatologists and meteorologists have to find the causes to explain this phenomenon.

Table 2. Results of the various statistical tests of detection of rupture applied to Pdmax.

Station	Studied periode	Segmentation de Pierre Hubert	Buishand	Pettitt	Lee et Heghinian
Annaba	**1950-1998**	**No Change**	**accepted**	**No Change**	**1998**
Dar el Baida	**1936-1998**	**1973**	**rejected**	**1956**	**1952**
Senia	**1927-1998**	**1970**	**rejected**	**1943**	**1935**
Bouhanifia bge.	**1967-1998**	**No Change**	**rejected**	**No Change**	**1995**
Beni Bahdel	**1941-2002**	**1974**	**rejected**	**1974**	**1974**
Guelma	**1967-2003**	**1975**	**rejected**	**1975**	**1975**
Batna ferme EXP	**1929-2003**	**No Change**	**accepted**	**No Change**	**2001**
Ain el Assel	**1967-2003**	**No Change**	**accepted**	**No Change**	**2000**
Jijel secteur	**1968-2003**	**No Change**	**accepted**	**No Change**	**1963**
Ain Roua	**1969-2002**	**No Change**	**accepted**	**No Change**	**2001**
Birmandrais ANRH	**1967-2004**	**1973**	**rejected**	**1973**	**1973**
Pont CW (Hadjout)	**1972-2003**	**1986**	**rejected**	**1986**	**1986**

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Climate change impact on the water resources of the semi-arid Jordan region

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Keywords: water balance, semi-arid regions, climate change, scenarios, TRAIN model

ABSTRACT

The paper deals with the simulation of current water availability and irrigation water demand in the semi-arid part of the Jordan River Region. It also includes an assessment of the impact of future climate change on the regional water resources. The investigations are based on the IPCC B2 scenario and cover the scenario period 2070–2099. First simulations indicate drastic changes in the future distribution and availability of the region's water resources. A projected ca. 11% decrease of future precipitation totals leads to simulated reductions in water availability of ca. 25%, and irrigation water demand would rise by about 22% in order to sustain agriculture at its current extent.

INTRODUCTION

In the framework of the "GLOWA-Jordan" project (www.glowa-jordan-river.de), an interdisciplinary and multinational group of researchers investigate the impact of climate and land-use change on the water resources of the Jordan Region. The area investigated in the hydrological sub-project includes the semi-arid part of the Jordan basin and its broader environs. Thus, it is stretching from the upper north of the Jordan basin to the Gulf of Aqaba in the south, and from the Mediterranean coast to the Jordanian Highland / Jordanian Plateau (Fig. 1), and covers a land area of approximately 90,000 km².

The Jordan River Region is ranking among the most water poor regions of the world. Over a distance of only 300–400 km a pronounced climate gradient occurs, with climate conditions changing from sub-humid in the north of the region (mean annual precipitation ca. 800–1000 mm) to hyper-arid at the Red Sea (mean annual precipitation less than 100 mm, potential evaporation > 2000 mm). The scarce water resources are competitively shared among several nations and different water use sectors, with irrigation agriculture as one of the major water users: Around 66% of the current water use is for irrigation purposes, and ca. 30% is used in the domestic sector (EXACT, 1998). These numbers are however unevenly distributed over the different countries. While the mean daily per capita domestic water use amounts to 250 litres in Israel, the related numbers for Jordan and the West Bank are 90 litres and 55 litres, respectively. An increasing population with a current number of ca. 16 million, rising water demands and an expected reduction in precipitation totals make the region susceptible to frequent droughts and future water conflicts.

Our investigations aim to assess the impact of both land-use and climate change on the water resources of the project region. They include selected field studies and hydrological simulations on different spatial scales, from the patch scale to the hydrological meso- and macro-scale (Fig. 1). The small to medium scale studies serve to further develop and validate the applied hydrological model regarding the representation of evapotranspiration, irrigation water demand, soil moisture and groundwater recharge. The application of the hydrological model to the macro-scale serves to carry out an areal analysis of the water balance elements and their modification by land-use and climate change. Therefore, the investigation considers two time periods: The reference period covers the years 1961–1990, while the scenario conditions refer to the period 2070–2099.

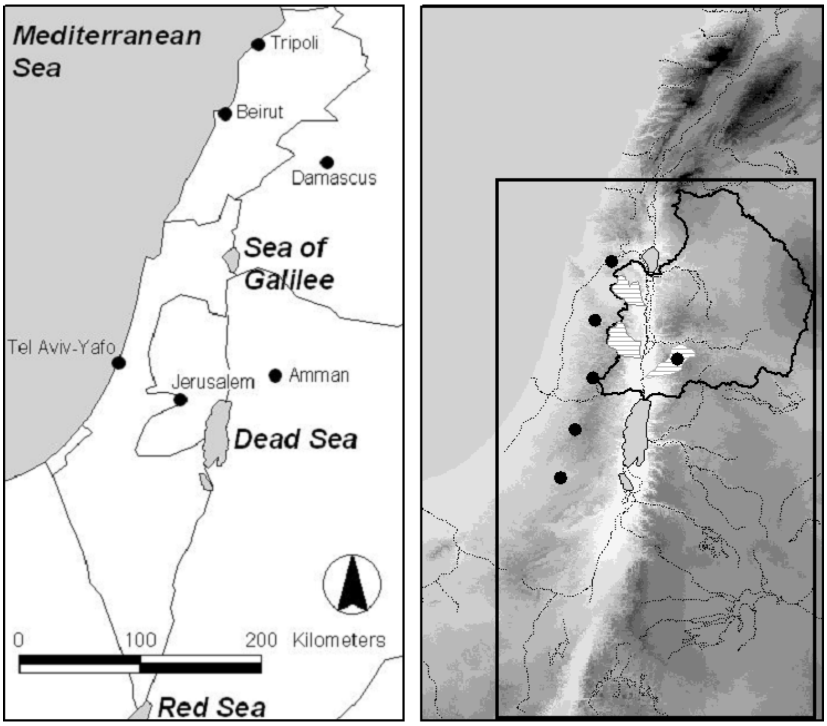

Figure 1. Overview of the Jordan River Region, including frontiers and big cities (left) as well as the topographical conditions (right). The square on the right graph encloses the actual project region and includes the semi-arid sub-basin of the Jordan River (located between the Sea of Galilee and the Dead Sea, with catchment borders drawn as solid line) as well as several experimental sites (black dots) and meso-scale research catchments (hatched)

METHODS

The investigations in the project region have been carried out with the hydrological model TRAIN. TRAIN is a physically-based, spatially distributed model which includes information from comprehensive field studies of the water and energy balance of different surface types, including natural vegetation and agricultural land. It has been designed to simulate the spatial pattern of the individual water budget components at different spatial and temporal scales. Typical applications are at the point and the regional scale, with temporal resolutions of one hour or one day. For an areal simulation of the water budget, the investigated spatial unit is subdivided into a regular grid, with square sizes dependent on the available input data and their spatial resolution (typically in the range of 1 x 1 km). Special focus in TRAIN is on the processes at the soil-vegetation-atmosphere interface, with evapotranspiration as one of the principal mechanisms. For the regionalisation of the water balance components specific local elements (topography, land-use, soils) and varying meteorological conditions are included in the calculation process (Figure 2).

At the core of the model is the simulation of transpiration through plants based on the Penman-Monteith equation (Monteith, 1965). It depends on the calculation of canopy resistances which are modified by the state of growth of the vegetation, soil moisture and weather conditions (Menzel, 1996). Interception and interception evaporation are simulated according to Menzel (1997). This approach subdivides the canopy into an optional number of layers from which the intercepted water can evaporate with different intensities. This is especially an advantage regarding the representation of water fluxes in dense canopies. In the case of poor soil information the calculation of the soil water status and of percolation follows a modified version of the conceptual approach from the HBV-model (Bergström, 1995). In other cases, the soil module includes the storage routing technique described by Arnold et al. (1990) which subdivides the soil into a number of discrete layers. The snow accumulation and snow melt schemes are based on simple, conceptual approaches, such as the degree-day equation. Melted snow is treated in the same way as rainfall for further calculation of infiltration/percolation.

Application of TRAIN for agricultural land includes the consideration of a number of different field crops and possible irrigation water demands. As soon as the soil water content falls below a critical limit, the model assumes the application of irrigation as long as a sufficient soil water status (usually field capacity) is not reached. The amount of water needed to compensate soil water stress is assumed to equal irrigation water demand.

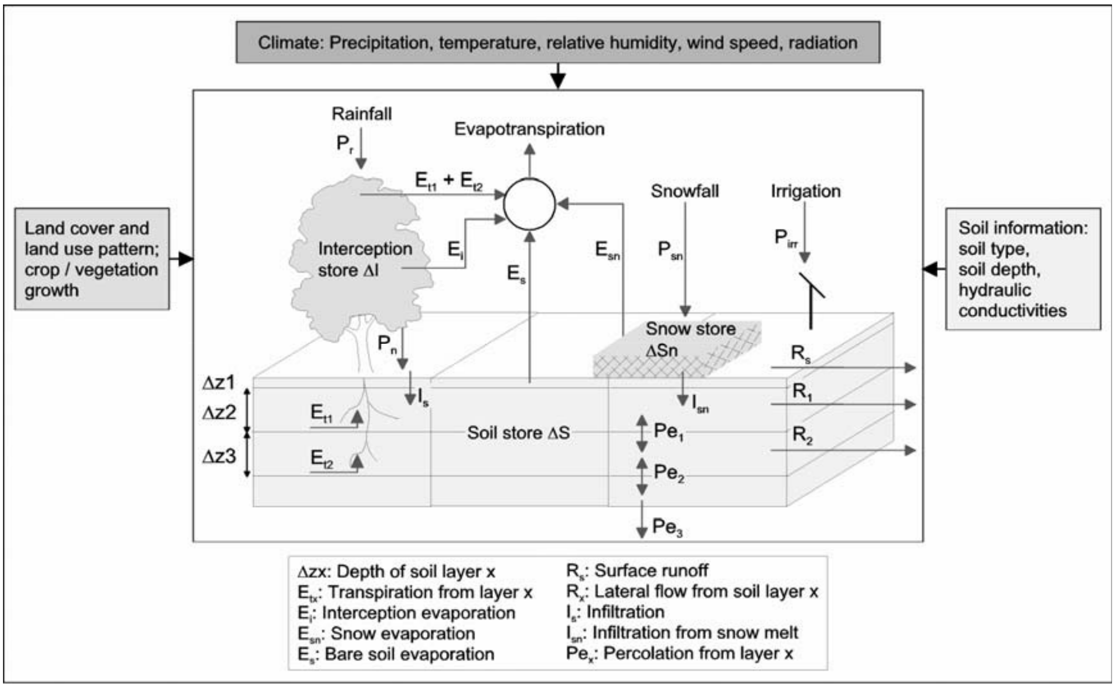

Figure 2. Overview of the TRAIN model, its input requirements, the simulated processes and the related output data

For an areal analysis of the water balance of the semi-arid Jordan region a series of data sets was required to drive the TRAIN model: Daily meteorological data (precipitation, air temperature, air humidity, wind speed and solar radiation) were adopted from MM5 climate model runs (see below). Information regarding topography was taken from the global Digital Elevation Model (DEM) GTOPO30 (USGS, 2007a) with a horizontal grid spacing of 30 arc seconds (approximately 1 km). Since no integrative, consistent land-use and soil data base was available for the three countries of the project region, respective global data sets were applied. Land use information came from the Global Land Cover Characterization GLCC (Loveland et al, 2000; USGS, 2007b) with a grid size of 1 x 1 km. Data from the Soil Map of the World database (FAO, 1991) with a 5 arc second spatial resolution were combined with predictions of profile available water capacity as described in Batjes (1996). The DEM, the soil and land-use grids and the individual climate layers were re-projected to congruent grids and aggregated to a common spatial resolution of 18 x 18 km. This was necessary since the data delivered by the climate model were available at this resolution, thus allowing only a comparatively coarse areal analysis. However, information on sub-grid variability was taken into account, i.e., TRAIN was iteratively run for individual grid cells which contain heterogeneous soil and land-use conditions.

Meteorological time series for both the reference period 1961–1990 and the scenario period 2071–2099 were delivered by the Institute for Meteorology and Climate Research IMK-IFU (http://imk-ifu.fzk.de/) on a 18 x 18 km grid. They are based on multiple runs of the limited-area, meso-scale climate model MM5 (MM5, 2007) which was driven with boundary conditions from the Global Climate Model ECHAM4 (Roeckner at el, 1996) and thoroughly tested against observations available for the project region. The climate scenarios are based on the IPCC A2 and B2 emission scenarios. In the present paper, focus is only on results of the B2 related scenario data since climate model output was not available yet for A2.

RESULTS

Figure 3 presents the mean monthly rainfall distribution in the focus area, calculated using daily data generated by the MM5 model. Data are shown for both the reference and the scenario period. In general, rainfall is very unevenly distributed over a year, with a clear maximum during winter and practically no rainfall during the summer months (Fig. 3). According to the applied climate scenario, this inter-annual variability will be preserved in the future, but the mean annual rainfall totals are projected to decrease – from 141 mm during 1961–1990 to 125 mm during the scenario period. According to the scenario, mean monthly rainfall is projected to increase during May, June and October; however, the absolute changes are small and they are considered to lie within an estimated uncertainty range.

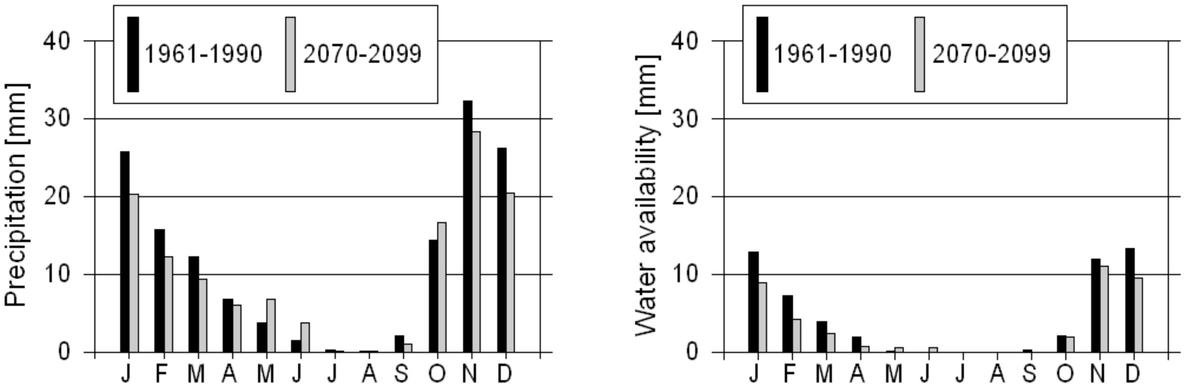

Figure 3. Overview of the water resources of the investigated region and their modification by climate change. The figure shows mean monthly precipitation totals (left) and mean monthly water availability (right) for both the reference and the scenario period, the latter based on IPCC’s B2 emission scenario. Precipitation data come from the MM5 model while water availability is generated using output from TRAIN

Figure 3 also shows the water availability simulated by TRAIN (understood here as a combination of cell specific groundwater recharge and runoff). In comparison to the rainfall data, water availability is much lower and exceeds a mean monthly threshold of 10 mm only during November–January of the reference period (Fig. 3). With the B2 climate scenario, water availability is simulated to decrease, with a reduction of mean annual totals from 54 mm during 1961–1990 to 40 mm during 2070–2099. The analysis clearly demonstrates the water scarcity in the region and that there seems to be a tendency towards a further reduction of water availability within the next decades. It should also be pointed out that the diagrams of Figure 3 show aggregated data over the whole project region (Fig. 1). It is clear however that several sub-regions suffer an even higher water shortage. The large difference between the precipitation and water availability data clearly demonstrates the importance of evaporative processes in the focus region.

Figure 4 presents further results regarding the impact of climate change on the area investigated. As in Figure 3, it can be stated that the projected reduction of mean annual precipitation (based on the MM5 model output, driven by the B2 emission scenario) leads to an over-proportional decrease of water availability in the region. Figure 4 reveals however that actual evapotranspiration is simulated to increase by 2% only. The reasons for this developments are as follows: Precipitation is projected to decrease relatively uniform over the project region. In the extremely dry, southern parts of the region, at the edge of the Negev desert or in the Negev itself, water availability is close to zero already under current climate conditions. A further decrease of precipitation doesn’t therefore lead to any reduction in water availability in those regions. However, our simulations show a clear reduction in actual evapotranspiration. In the more humid, northern parts of the region and along the coastal plains, a reduction of precipitation leads to a strong decrease in water availability while actual evapotranspiration is projected to increase. Therefore, the inhomogeneous changes in evapotranspiration across the region are more or less balanced out in the aggregated view presented in Figure 4. In contrast, a strong net decrease follows for the water availability.

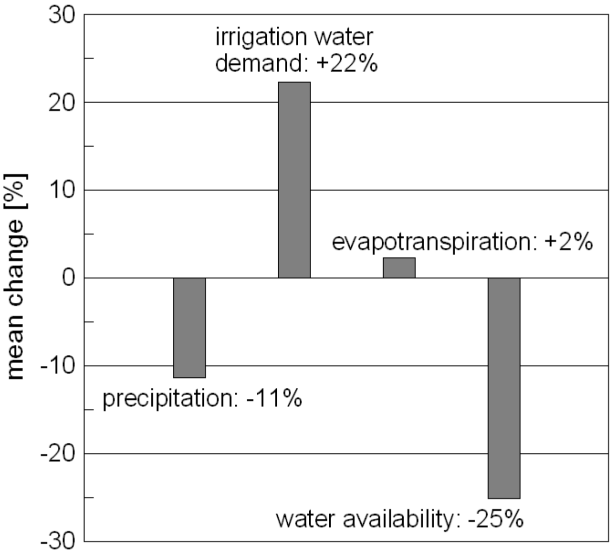

Figure 4. Aggregated results of the B2 scenario study for the investigated region. The graph depicts relative changes of the major water balance components and of irrigation water demand for the scenario period 2070–2099 in comparison to the reference period 1961–1990

Under the assumption of an unchanged extent and intensity of irrigated agriculture, the reduction in water availability would need to be adjusted by additional irrigation. Therefore, irrigation water demand is rising by the large, relative amount shown in Figure 4. The result doesn't argue however that this additional amount of water will be available under the future, obviously more water scarce conditions.

DISCUSSION AND CONCLUSIONS

The results presented in this study come from a first estimation of current and future water resources in the Jordan region and thus need to be considered as preliminary. They include several simplifications and assumptions as well as coarse datasets. Refinements and model improvements will be iteratively included in the simulations, and additional climate scenarios will be considered in order to give an uncertainty range regarding the possible future development of the water resources.

Given the discussed uncertainties, our study shows that the project region will very probably experience higher levels of water stress in the future. Even the relatively moderate B2 climate scenario results in a drastic decrease in water availability while irrigation water demand would rise accordingly in order to sustain agriculture at its current extent. Since the population numbers of the region are also projected to increase, a further rise in domestic and industrial water demand can be expected in the future. It is however very unlikely that additional freshwater resources will be available to close the gap between rising water demands and decreasing water availability. Options, such as seawater desalination, rainwater harvesting or wastewater irrigation are not considered in this study, but it is planned to include them in one of the next steps of the project. In any case, the investigations indicate that irrigated agriculture will very probably come to its limits under drier conditions. Scenarios of land-use change, such as a reduction of agricultural land, will soon be included in our investigations. Our study also aims at initiating and supporting measures towards an Integrated Water Resources Management in the region. However, this will only be successful when all affected parties are included.

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Regionalisation of Slovak rivers with respect to climate change in 1930–2005 and their sensitivity to QBO and NAO phenomena

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Keywords: Regionalisation of the flows, long-term variability; trends; cyclicity; Slovakia

ABSTRACT

The analysis of the long-term discharge series of Slovak rivers helped to identify three regions within the territory of Slovakia with different surface water resources threaten by NAO, AO and QBO phenomena as well as expected climate change (high, middle, and low). The runoff analysis of Slovak rivers is based on 36 series of mean monthly discharges (period 1931–2005). We selected 28 stations with low anthropogenic influences, i.e. with preserved natural regime. Standardized monthly runoff was calculated from mean monthly data. The standardized series were used to calculate the 84-month moving averages (7-year moving averages), in order to filter the extreme values. Based on the smoothed data we identified 3 regions with similar runoff changes. The decrease of runoff in 1980`s-1990's is related to 13-years period of dry years in Slovakia in 1981–1993 and low territorial precipitation in Slovakia due to positive NAO phase. Second part of the paper deals with the spectral analysis of mean monthly discharge series in individual regions. We identified following cycles 1.7-; 2.35-; 3.6-; 5-; 13–14-; 21-; 30- and 36-years. The main cycles of the QBO, NAO, AO and ENSO indices are found by combined periodograms and are compared with the length of the runoff cycles. Cycles of similar length occur in both series. The relation is shown for Slovak rivers between runoff and NAO series, as well as between runoff and ENSO series. Cycle of 2.4 years is probably related to QBO phenomenon, cycle of 3.6 years with ENSO and NAO phenomenon, and 30-years cycle is probably a signal of AO phenomenon.

INTRODUCTION

Expected impact of the climate change upon the hydrological regime and runoff variability is one of the key issues of the hydrology. Several methods exist for identification of long-term trends and multiannual cyclicity. The most simple is the identification of cyclic component by statistical filters. We used moving averages technique for identification of dry and wet periods.

The unusually long dry period occurred in Slovakia in 1980's - 1990's. In Fig. 1a are the double 7-years moving averages of annual precipitation in Slovakia. The occurrence of dry and wet periods is related with dry and wet periods in Danube discharge series. The Slovak river basins belong to the Danube basin. In Fig. 1b is the plot of double 7-year moving averages of the Danube discharges from 2 stations: Bratislava (Slovakia) and Turnu Severin (Romania). Station Bratislava represents the upper Danube discharge, and Turnu Severin station the upper and middle Danube. The wet and dry periods are easy to be identified at the graph. The occurrence of the individual periods is identical along the whole Danube river stretch. The data from the station Turnu Severin are very important for the trend analysis, as they are collected in a rocky profile since 1840 and we can trust them. In Fig. 1c the course of double 7-year moving averages of air temperature is drawn (three stations). We can see that the dry periods in Danube series are related with local air temperature maxima in Central and Eastern Europe. Since 1860 the air temperature is increasing, while in the Danube River we can not observe increase or decrease of the runoff (long term linear trend of Danube runoff is constant). The results indicate that the periods around the year 1860 and 1990 were the driest periods in the Eastern Europe (and also in Slovakia) since 1840. It is interesting to notice that in the period around the year 1860 the mean annual air temperature in Europe was lower by about 0.6°C compared to the 1990s`. Figure 1d shows that dry periods in Danube series are related with high values of AO index.

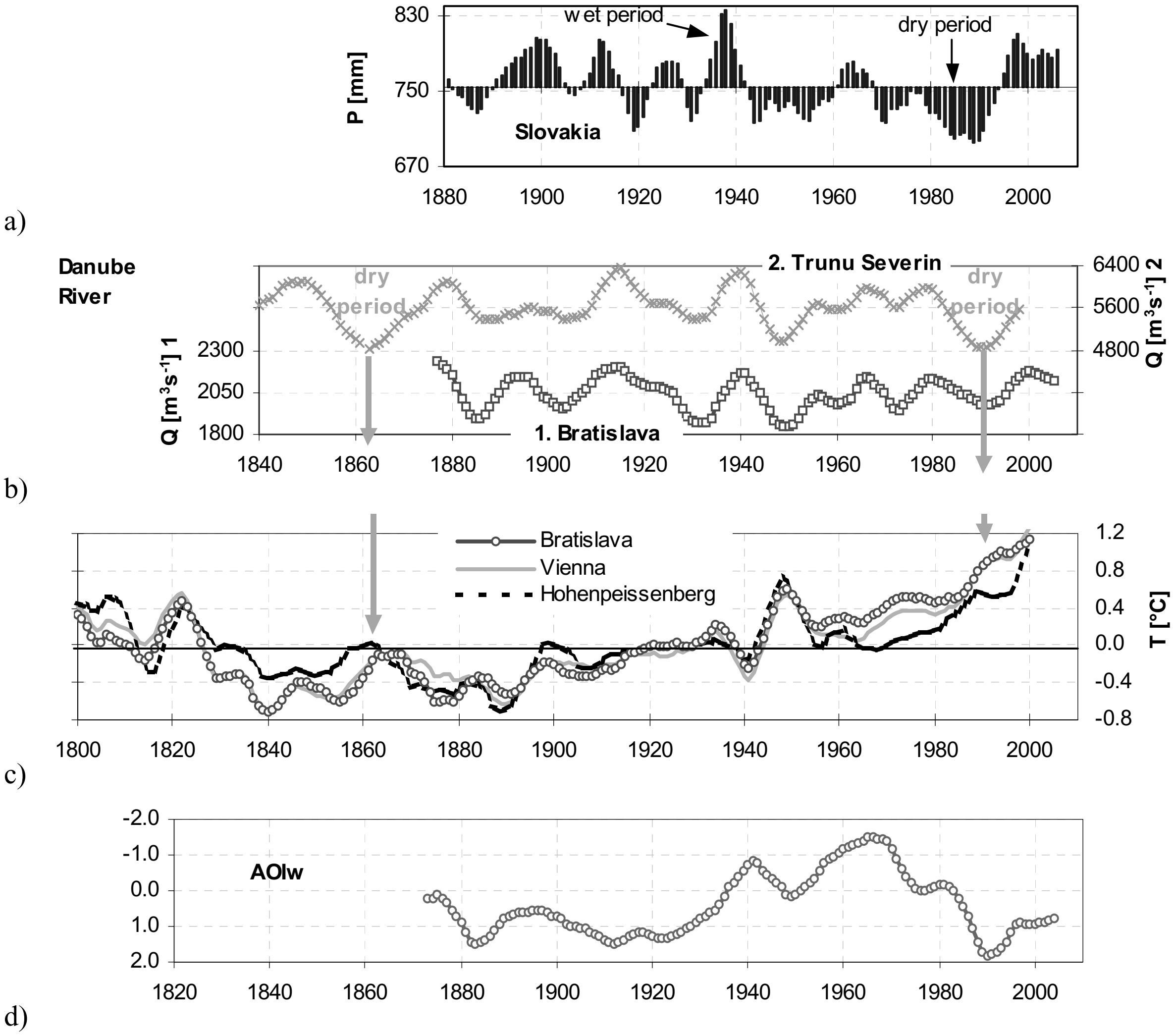


Figure 1. Occurrence of dry and wet periods in Slovakia and in the Danube river basin.
a) Course of double 7-year moving averages of annual precipitation in Slovakia;
b) Course of double 7-year moving averages of the Danube discharges from 2 stations: Bratislava (Slovakia) and Turnu Severin (Romania);
c) Course of double 7-year moving averages of air temperature in three stations;
d) Course of double 7-year moving averages of AOI.

Regionalisation of the flows based on long term runoff trend

It is essential to use as long data series as available for the regionalisation. Thirty-six river basins in all regions of Slovakia were included into the National Climate Program (NCP) with the aim to assess the possible climate change impact upon the water management (Majerčáková & Minárik, 1994). Selection of the basins was done with respect to the length of the data series, quality of the data and anthropogenical influence. We selected 28 out of the NCP rivers and processed the mean monthly data 1931–2005 from the database of the Slovak Hydrometeorological Institute.

The 84-month moving averages (7-year moving averages) were then calculated from the standardised series in order to filter the extreme values and the linear trend was evaluated. The standardised monthly runoff was calculated from the mean monthly data series.

According the linear trend (slope *b*) of the processed series we detected three regions (Figs. 2, 3) with similar development of the runoff trend. In the region I. no decrease of runoff is observed in 1931–2005. In the region II. (central Slovakia – left hand tributaries of Váh, tributaries of Nitra, Hron, upper Poprad) we can observe slow decrease of runoff in 1931–2005 (slope between –0.0001 to –0.0006). In the region III. (lowland rivers) is the decrease of the moving standardised flows in 1931–2005 more significant, especially in case of small streams (Stitnik, Dobsinsky potok).

It follows from the analysis of the long term trends of the Slovak rivers in 1931–2005 (Fig. 3) that the 1990s` was the driest decade in the history of runoff observations in Slovakia. The occurrence of drier years in the pre-instrumental period can be confirmed only indirectly by the analysis of longer data series of the Danube River (Fig. 1).

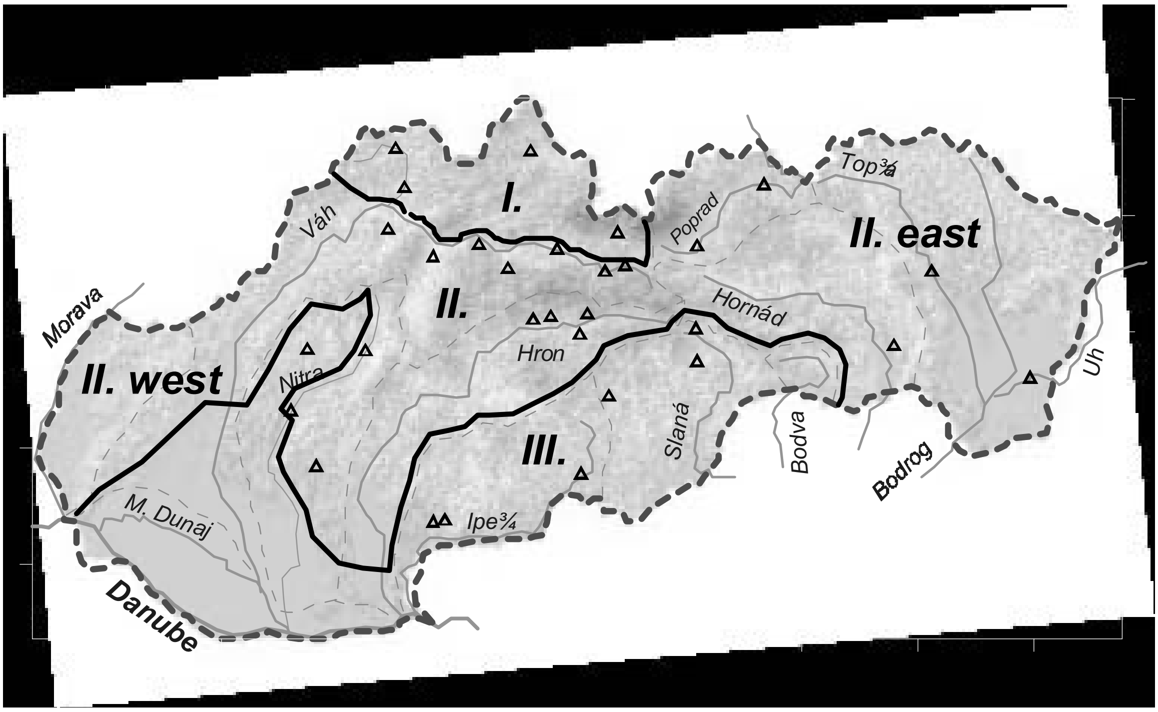
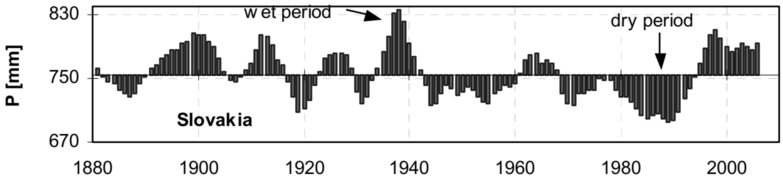
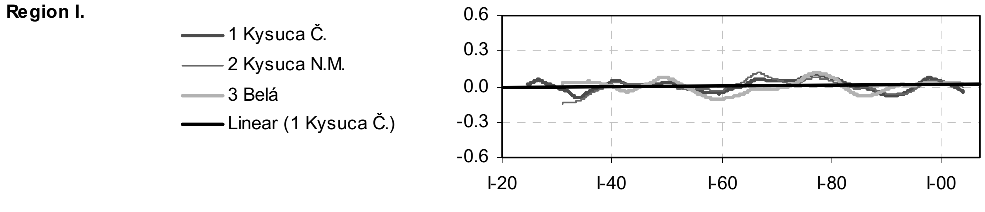


Figure. 2. Regionalisation of the Slovak flows according to long-term runoff trend.





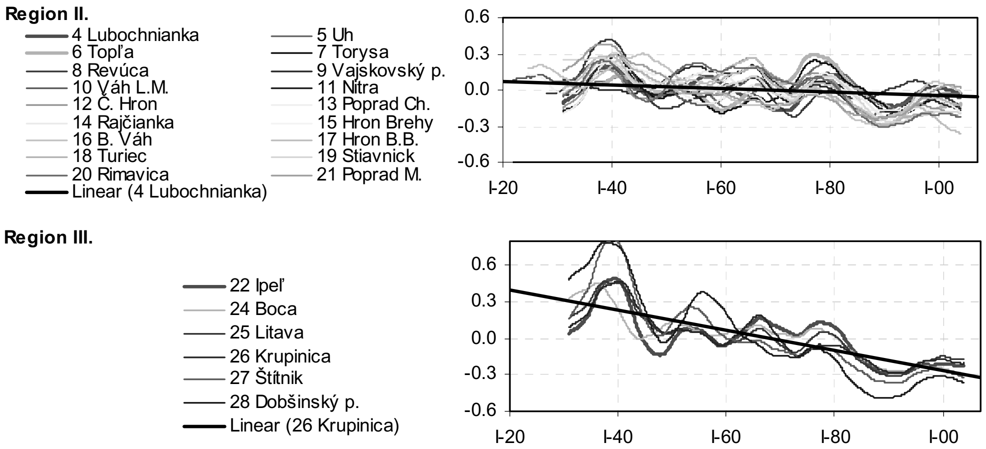


Figure 3. Regionalisation of the Slovak rivers according to long-term runoff trend.
Course of double 7-year moving averages of annual precipitation in Slovakia – upper graph; double 7-year moving averages of discharges in individual three regions.

Spectral analysis and teleconnection of the Discharge series and NAO, AO and QBO phenomena
We used the method of spectral analysis - combined periodogram (Pekárová et al., 2003, 2006) for identification of the length of cycles in the mean runoff series, as well as NAO, AO and QBO phenomena. In Fig. 4, there are presented the combined periodograms of the annual runoff of the Bela: Podbanske (region I) and Cierny Hron (region II), and combined periodograms of QBOI and NAOI. The lengths of cycles we found in the series are: 2.35-; 3.6-; 5-; 13–14-; 21-; 30- and 36-years.

In Fig. 5, the combined periodogram of annual discharge of the Hron River at Brehy station is presented as well as the autocorrelogram of monthly discharge. On the basis of the previous analyses we suppose that the 28-month period in the discharge time series is connected to the QBO cycle. While all the periods 3.65-; 7–8- and 14–15-year are connected to the AO phenomenon, only some of them are connected to the NAO and SO phenomena.

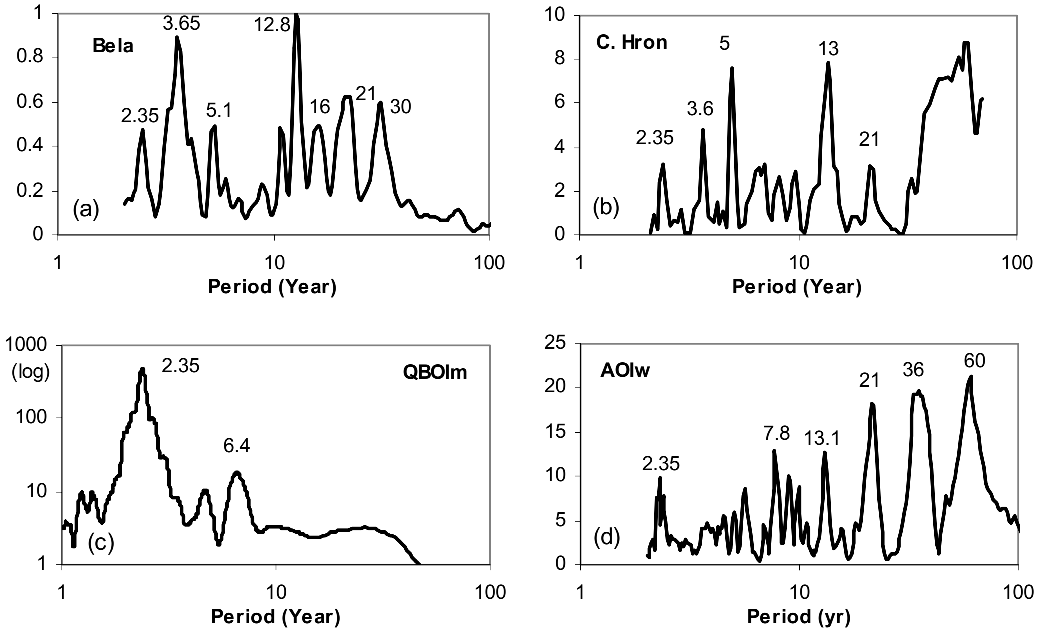


Figure 4. Combined periodogram of the:

a) Annual discharge time series of Bela River (1895–2003).
b) Annual discharge time series of Cierny Hron River (1930–2003).
c) Quasi-Biennial Oscillation Index (QBOIm), monthly time series for period 1953–2001 according to Marquardt and Naujokat (1997).
d) Winter Arctic Oscillation Index (AOIw) according to Li & Wang (2003). Long term trend removed.

CONCLUSIONS

The analysis of 28 runoff series of the Slovak rivers for the period 1931–2005 has shown that according to the long-term runoff trend we can distinguish 3 regions on the territory of Slovakia. The first region is without significant runoff trend, the second one covers mainly the Central Slovakia (slow decreasing trend) and the third one is in the lowland areas of the Southern Slovakia (rapid decreasing trend).

The Slovak territory is hit by a border line (from Marseille to St. Petersburg) between the North-western Europe, where is no decrease of runoff, and South-eastern Europe, where the runoff trend was decreasing till 1995 (Krichak et al., 2002; Mariotti, 2002).

During the analysed period 1931–2005 (Fig. 1) the driest decade were 1990s`. With the help of the longer series of Danube in Turnu Severin it was shown that the driest period in the Central and Eastern Europe and also in Slovakia was the period around the year 1860. It was at the very beginning of the instrumented measurements and before the beginning of the climate change. In that period was the mean annual air temperature in Europe lower by about 0.6°C compared to the 1990s`. This temperature difference is usually assigned to the climate change. We can therefore assume that the long-term runoff variability has its own dynamics connected by precipitations variability. The cycles of alternating wet and dry periods in Slovakia were searched by filtering of the data series and using the spectral analysis (method of combined periodogram).

The results of the spectral analysis can be generalised as follows:

- Following cycles are overlapping in the runoff series of the main Slovak rivers: 1.7-; 2.35-; 3.6-; 5-; 13–14-; 21-; 30- and 36-years;
- Other longer cycles (e.g. 52-years, 104-years) probably occur in the series as well, but we are not able to detect them because of the short data series and to approve the hypothesis.

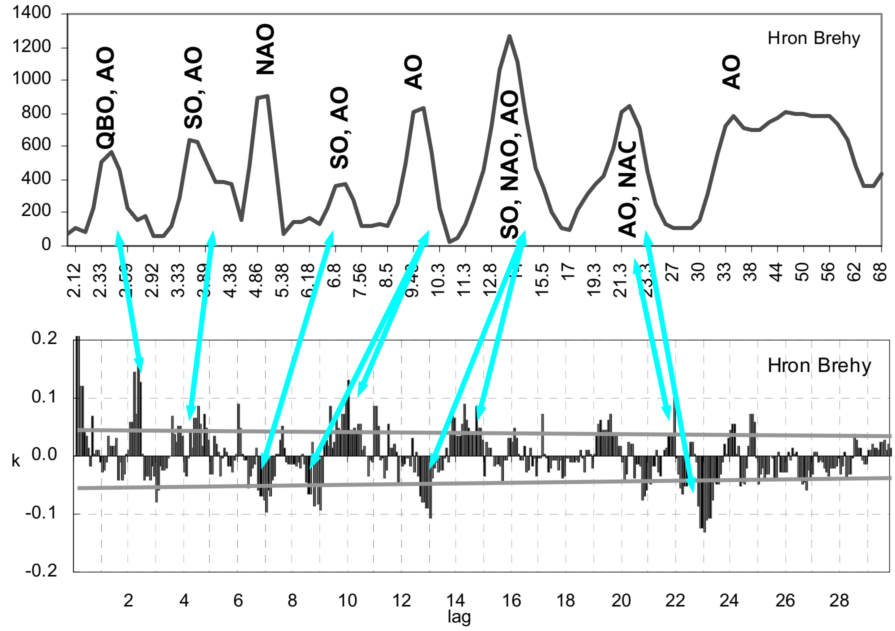


Figure 5. Teleconnection of discharge and QBO, NAO, AO and SO phenomena.

Combined periodogram (up) and autocorrelogram (bottom).

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Hydrological Extremes in the IPCC AR4

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Keywords: climate change, hydro-meteorological extremes, IPCC, uncertainty, vulnerability and adaptation

ABSTRACT

Climate change will emerge as one of the formidable environmental challenges that hydrologists/water resources practitioners will face in this century and beyond. The planet earth is already warming up at an accelerated rate due mainly to human activities. In many parts of the world, extreme hydrological events are on the rise; so as the physical and economic damage. Sea level is also rising and projected to be increased at a faster rate than ever before. Glaciers are melting in the Himalayas and in many other places, posing increased risk to water supplies, energy production and glacier lakes outburst floods (GLOFs). This paper is based on results of a thorough scanning of hydrological events and their treatments in the IPCC WGI and WGII reports for its Fourth Assessment (AR4). Although there are uncertainties about extreme hydrological events, WGI of the IPCC treated them more confidently in the AR4 than its Third Assessment Report (TAR). WGII treated extreme hydrological events more extensively in the AR4 with regard to vulnerability and adaptation across sectors and regions. This paper also explores and maps regional differences in occurrences of extreme hydrological events, vulnerability and adaptation.

INTRODUCTION

There is a growing public concern that extreme hydrological events-floods, droughts and cyclonic storm surges are on the rise. Although, it is difficult to directly correlate increases of these hazards with climate change, awareness in the scientific and policy making communities are growing. According to Munich Re (2007), 91% of the losses that occurred in 2006 were weather related and fatalities were comparable with the long-term average. The Munich Re (2007) has identified 13 extreme hydrological events in 2006 that killed at least 6,320 people and caused enormous economic damages (Munich Re, 2007).

Among the hydrological extremes, floods are thought to be the most destructive; spatially extensive. According to Red Cross, in recent years, among all categories of natural disasters, floods are the most common reported events in Africa, Asia and Europe. First two continents are in tropical regions where extreme rainfall events are common; but floods are encroaching to new areas in these two continents too. On 26 July 2005, Mumbai-the financial capital of India experienced 944 mm rain within a span of less than 24 hours which was 42% of mean annual rainfall. This unprecedented rainfall event caused severe flooding and death toll exceeded 1,000 and economic damage was estimated to be US$ 2200 million (Bohra *et al.*, 2006). In Africa, Ethiopia has been a chronic drought affected country but in 2006 floods engulfed Ethiopia twice and killed more than 1700 people (Munich Re, 2007). In recent years, floods have found a new home-Europe. In Central Europe, river flooding is recognized as a major hazard particularly after the 1997 Odra/Oder flood, the 2001 Vistula flood, most destructive deluge on the Labe/Elbe in 2002 (Kundzewicz *et al.*, 2005) and 2005 destructive floods in Austria, Bulgaria, Germany, Romania and Switzerland.

From 1994 to 2004, drought and famine, these two hazards disasters proved to be the deadliest disaster worldwide; they claimed at least 275,000 deaths since 1994 - nearly half the total for all natural disasters in the same time period (IRCRCS, 2005). In the same decade, drought and famine claimed over 1,000 lives per reported disaster, while extreme temperatures claimed over 300 lives per disaster.

While the scientists are still arguing about the discernible trends in extreme hydrological hazards, their links with climate change, etc., worldwide economic damages are increasing. For example, Munich Re (2004) estimated economic losses increased by seven folds in the period 1994-2004 compared to that of 1960-1969. In the same period, insured losses were increased by 15 folds. For at least three major reasons economic losses are on the rise. They are: *First*, inflation pushes prices of goods up; *second*, except for periods of recession or depression, people and institutions have a general behavior to acquire more wealth through time (Katz and Herman, 1997); increases in per capita income due to globalization and market reforms in many parts of the world including highly vulnerable developing nations (Mirza, 2005) and *third*, population increases as well as increased human tendency of moving areas vulnerable to natural hazards inspired by aesthetic reasons, risk perceptions, and public policies.

APPROACHES TO SYNTHESIZE INFORMATION

The IPCC has been established by WMO and UNEP in 1988 to assess scientific, technical and socio-economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation. The IPCC has three Working Groups (WG) with distinct mandates and objectives. **WGI** assesses the scientific basis of climate change. **WGII** conducts assessment of the scientific, technical, environmental, economic and social aspects of the vulnerability (sensitivity and adaptability) to climate change of, and the negative and positive consequences for, ecological systems, socio-economic sectors and human health, with an emphasis on regional sectoral and cross-sectoral issues. **WGIII** is entrusted with task to assess available information on the science of climate change, in particular that arising from anthropogenic activities. This group is concerned with the scientific, technical, environmental, and economic and social aspects of mitigation of climate change. Therefore, the approach should be crafted in accordance with the contents of reports of three working groups. Kundzewicz and Schellnhuber (2004) proposed scanning information of floods from the IPCC's Third Assessment Reports based on three characteristics: (1) climate and atmospheric systems; (2) terrestrial systems (hydrological systems and ecosystems); (3) economic and social systems. However, hydrological extremes can be looked at from two other angles: risk, vulnerability and adaptation and mitigation and stabilization of greenhouse gases. A large number of important variables which the IPCC treated in its reports are as follows:

(i) Climate and atmospheric systems

-extreme temperature
-total precipitation
-intensity and duration of precipitation
-wind speed (hurricanes/cyclones/typhoons
-ENSO (El Niño and La Niña events)
-storm surge heights
-sea level (rise and fall)

(ii) Terrestrial System (hydrological systems and ecosystems)

-High and Low flows (magnitude, frequency, duration and seasonality
-water level (high and low)
-water storage capacity (loss due to sedimentation, encroachment to wetlands)

-infiltration capacity (loss due to deforestation, urbanization, etc.).
-Water quality
-flow variability and effects on ecosystems
-Erosion and sedimentation

(iii) Economic and Social Systems

-anthropogenic pressure
-multiple stressors (globalization, HIV/AIDS)
-water related diseases and public health
-income and inflation
-insurance and other policy incentives
-gender and social classes
-environmental refugees

(iv) Vulnerability and Adaptation

-risk and its perception
-degree of exposure
-coping capacity
-adaptive capacity
-governance
-mainstreaming
-opportunities and constraints

(v) Mitigation and stabilization

-mitigation (GHGs)
-stabilization scenarios

OBSERVED CHANGES IN CLIMATE AND HYDROLOGICAL EXTREMES: WHAT ARE NEW

The recently released WGI Report (IPCC WGI, 2007a) of IPCC AR4 has stated that warming of the climate system is unequivocal which is presently evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Following few selected findings of observed changes.

- Eleven of the twelve years from 1995-2006 rank among the 12 warmest years in the instrumental record of global surface temperature since 1850. The updated 100-year linear trend from 1906 to 2005 is 0.74°C [0.56°C to 0.92°C]. This is larger than the what [0.6°C/100 years] was reported in the TAR.
- In both northern and southern hemispheres, widespread decreases in mountain glaciers and snow cover have been observed which have contributed to sea level rise. The late 20th-century glacier wastage likely has been a response to post-1970 warming. The biggest contributions to sea level rise came from Alaska, the Arctic and the Asian high mountains glacier losses (IPCC WGI, 2007a, p. 339).
- In the last 35 years (1970-), more intense and longer droughts have been observed over wider areas in the vulnerable continents. Two important climatological factors-*large surface warming* and *decreased land precipitation* since 1980s have been found to have linked with increased drying (IPCC WGI, 2007b, p.316). In addition to these, changes in sea surface temperatures, wind patterns and decreased snowpack and snow cover have also been linked to droughts.
- The frequency of heavy precipitation events has increased over most of the land areas. This finding is consistent with warming and observed increases of atmospheric water vapor. For the continental USA, statistically significant increases in heavy (upper 5%) and very

heavy (upper 1%) precipitation of 14 and 20%, respectively were observed. The relative increase in precipitation extremes is larger than the increase in mean precipitation in the USA and Europe , and manifested as an increasing contribution of heavy events to total precipitation ((IPCC WGI, 2007b, p. 302).

CLIMATE AND HYDROLOGICAL EXTREMES: FUTURE PROJECTIONS

The IPCC AR4 has a higher confidence than before about projected patterns of warming and other regional-scale features that include changes in wind patterns, precipitation and some expects of extremes and of ice (IPCC WGI, 2007a, p.15). On the future patterns of warming, it has stated that even if the all radiative forcing agents are kept constant at year 2000 levels, a further warming of about 0.1oC per decade would be expected. For a range of SRES emission scenarios, a warming of 0.2°C/decade is projected for the next two decades (IPCC WGI, 2007a, p.12). Salient features of the IPCC AR4 findings are:

- It is *very likely* ((>90%) that frequency of hot extremes, heat waves and heavy precipitation will continue to increase. Heat waves will be longer lasting heat waves will be more intense and longer lasting. Intensity of precipitation will increase in tropical and high latitude areas that experience increases in mean precipitation (IPCC WGI, 2007b, p. 750).
- Future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds accompanied by heavy precipitation. But IPCC AR4 is slightly less confident (>66%) about projected models' result (IPCC WGI, 2007b, p.786). A poleward move of extra tropical storm tracks is also projected.
- An increase in precipitation is projected in the Asian monsoon (along with an increase in interannual season-averaged precipitation variability) and the southern part of the West African monsoon as well as an increase in the Australian monsoon in southern summer. Some decreases in precipitation are expected in the Sahel in northern summer (IPCC WGI, 2007b, p.778).
- Sea level rise is projected to increase (relative to 1980-1999) from 0.18 m to 0.59 m for a range of SRES scenarios. The ranges are narrower in the AR4 than the IPCC TAR due mainly to improved information of some uncertainties involved with the projected contributions. However, it is very likely that for all scenarios, the average rate of rise during the 21st century *will exceed* the 1961 to 2003 average rate (1.8 ± 0.5 mm yr–1) (IPCC WGI, 2007b, p.751).

HYDROLOGICAL EXTREMES: VULNERABILITY, IMPACTS AND ADAPTATION

Vulnerability, impacts and adaptation (VIA) with regard to hydrological extremes are discussed in IPCC WGII report. The assessment is made based on results of hydrological model runs and analyzing various socio-economic policies. WGII dealt VIA sectorally and regionally. Following impacts of some hydrological extremes on four key economic sectors: agriculture, water, human health and industry, settlement and society are summarized SPM-2 (IPCC WGII, 2007).

Sectoral Impacts

- More frequent hot days will have effects on water supplies of rivers that depend on snowmelt (Very likely);
- Heat waves will increase water demand, and reduced water quality (Very likely).
- Heavy precipitation will cause flooding which eventually cause damage crops, affect surface and groundwater quality, disruption of settlements, transport and societies and rural and urban infrastructures (Very likely).
- Droughts will cause land degradation, lower crop yields, increased deaths of livestock and increased risk of wildfire; expected widespread water stress; increased risk of hunger and water and food borne diseases; reduced hydropower generation potentials, etc. (likely).
- Higher risk of exposure of coastal areas; increased erosion due to rising sea level.

Regional Impacts

- In the near future (2020) between 75 to 250 million people are projected to be water stressed in *Africa*. Droughts will substantially affect agriculture (high confidence).
- In *Asia*, increased risk of flooding in the short-run due to glacier melt as well as intensified monsoon. However, in the long-run water supplies to glacier fed rivers will decrease. Highly populated mega-delta areas will be at the risk of increased flooding from rivers as well as from sea level rise.
- Water stress will increase in southern and eastern *Australia* and in *New Zealand*'s some eastern regions.
- *Europe* will experience increased risk of flash flooding, more frequent coastal flooding and erosion due to storminess and sea-level rise; The southern Europe will suffer from drought, water stress and reduced hydropower potentials. Higher water stress is also expected in Central and Eastern Europe.
- In *Latin America*, increased salinization and desertification are projected in the dry areas. Low-lying areas will be at risk of flooding from sea level rise. Changes in precipitation patterns and disappearance of glaciers will affect human consumption, agriculture and energy generation.
- In *North America*, coastal pollution will increase.
- In the Small Island States, inundation, storm surge, erosion, etc. could be exacerbated by sea-level rise. Increased temperature and changes in precipitation regime will reduce water resources availability by 2050.

Adaptation to Hydrological Extremes

Some adaptations to climate change extremes are occurring now that include floods, droughts, water scarcity, etc. Examples include prevention of glacial lake outburst flooding in Nepal and water management strategies in Australia.

Many adaptation measures are available now but more extensive adaptation will be required to reduce vulnerability to future extremes. Many regions will require structural interventions against riverine and coastal flooding as well as for drought management. Strengthening of non-structural measures will save lives and property. However, there are challenges ahead because there are barriers, limits and costs which are not presently fully understood.

CONCLUSIONS

Whatever measures we adopt now to reduce emissions of greenhouse gases, climate change is inevitable. In a changed climate regime, hydrological extremes like floods, droughts and storm surges will very likely to increase in many parts of the world especially in those regions which are now vulnerable to these hazards. Asian Mega Delta region will be more vulnerable to riverine and coastal flooding; the latter one will be exacerbated by sea level rise and possible increases in frequency and intensity of cyclones and typhoons. Vulnerability of Europe to both floods and droughts will increase. This is a significant finding since the IPCC TAR. The AR4 has identified a large number of adaptation practices to hydrological extremes; but there are barriers, limits and costs which need to be thoroughly researched.

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Hydrology for the 21st Century

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ABSTRACT

In the last 75 years hydrology as a science and as a profession has made tremendous progress. The progressive development of the hydrological science has contributed to the human well-being through flood and drought mitigation, boosting agricultural production and reducing food insecurity and hunger, identifying sources of pollution and its processes, design of safer communications, planning of sustainable urban areas, etc. Extreme weather events and their variability pose constant challenge to hydrologists. Climate change is another emerging issue that will have significant impact on hydrology as a science and also as a profession. Future climate change will have significant impact on water resources and extreme hydrologic events such as floods and droughts and their management through alteration of hydrologic cycle, monsoon intensification, excessive sediment and pollutant flows in runoff, etc.

Hydrologists can significantly contribute to achieve Millennium Developments Goals (MDGs). Many of the MDGs are directly related to the three major foci: water use, water control and pollution control. Satellite and remote sensing technology are advancing very fast. Although we see a very limited use of input data from these sources into hydrologic models, in future hydrologists can be significantly benefited from these technologies. Most of the hydrologic models are designed and built with a single purpose in mind. In a complex hydrological world, it is desirable to design and implement multipurpose integrated hydrological models. As an earth science, hydrology is closely related to other natural sciences –climatology and meteorology, soil science, geomorphology, fluid mechanics, etc. Despite developments in hydrology as a science, a big gap persists among the hydrologists and other associated professionals.

INTRODUCTION

Since the development of Richard's equation for unsaturated flow in early 1930s, the science of hydrology tremendously developed in the last 75 years. Maidment (1992) classified the development into four broad categories namely: the hydrologic cycle, transport, statistics, and technology. In early few decades, developments broadly occurred in the former three categories. However, in recent decades, most of the development is centered on technology such as models, geographic information systems (GIS), remote sensing and space science. Over the decades, it attracted huge number of graduates to pursue hydrology as a profession.

The science of hydrology and hydrologists have already significantly contributed to the society in many ways. World population has grown from 2.5 billion in 1950 to 6.4 billion in 2005. The growing population required a huge supply of food and fiber. Hydrologists helped assessing water resources and irrigation planning to boost agriculture production. However, other technological development such as fertilizer and seed also significantly contributed. Development in hydrology assisted in building safer communities through assessing flood processes, forecasting, estimating and modeling. Similar ways, it helped societies from the scourge of droughts. Pollution is another area where the hydrology tremendously contributed in terms of identification of sources, quantification and designing remedial measures.

As a science and profession, hydrology is facing many challenges in the 21st century. Extreme hydrological events are on the rise in many regions in the world. Damages from these events are also soaring. Sixty per cent of global ecosystem has either lost or degraded. In spite of rising concerns, environmental impact assessments and laws, pollution of surface and ground water sources are on the rise in many parts of the world. Water is becoming a scarce resource particularly in Asia and Africa. High seasonal variability in precipitation puts billions of people under water stress condition. Agriculture has reached at stagnancy even with rapid expansion of irrigation. Rain-fed agriculture has always been at the mercy of nature. Food security is becoming an issue of global concern. Climate change and sea level rise has emerged as one of the most pressing environmental issues of this century. Glaciers are melting at a faster rate than ever before. World water will likely be heavily impacted in terms of water supply and demand as well as more frequent visits of extreme hazards. In these contexts, this paper looks at the future of hydrology in the 21st century.

HYDROLOGICAL CHALLENGES

Increased Hydrologic Events and Damages

Hydrologists around the world are facing a daunting challenge of increasing hydrologic events especially floods (all forms) and droughts. In recent years, frequency and damages from floods and droughts have significantly increased (Munich Re, 2007). In 2005, inundation caused by Hurricane Katrina killed 1300 people in Atlantic Gulf Coast of the USA. Economic damage was in the magnitude of US$ 200 billion. In the same year, severe flooding in Mumbai, Maharashtra, killed 1,000 people and caused significant damage to the financial capital of India. In October and November 2006, the Horn of Africa experienced heavy precipitation- the region’s heaviest rains for 50 years and caused devastating floods in Ethiopia, Kenya and Somalia. During the last Indian monsoon, 24-hour precipitation readings broke records at many weather stations (Munich Re, 2007). It has identified 13 extreme hydrological events in 2006 that killed at least 6,320 people and caused enormous economic damages (Munich Re, 2007). According to Munich Re (2007), 91% of the losses that occurred in 2006 were weather related and fatalities were comparable with the long-term average.

Increased Pollution

Over the years, water pollution has emerged as a major issue in many parts of the world. Pollutants include pathogens, organic matter, nutrients, heavy metals and toxic chemicals, sediments and suspended solids, silt and salts (GEO, 2003). Water pollution comes from many sources, including untreated sewage, chemical discharges, spillage of toxic materials, harmful products leached from land disposal sites, agricultural chemicals, salt from irrigation schemes, and atmospheric pollutants dissolved in rainwater (ADB, 1999). South Asia - particularly India - and Southeast Asia are facing severe water pollution problems. Rivers such as the Yellow (China), Ganges (India), and Amu and Syr Darya (Central Asia) top the list of the world's most polluted rivers (World Commission on Water, 1999). In its annual report released in 1999, the Manila-based Asian Development Bank (ADB) said that some 830 million people in developing Asia and the Pacific did not have safe drinking water, and more than 2 billion people lack sanitation facilities. It projected a dramatic increase in water pollution in the Asia-Pacific Region in the first decade of the 21st century.

Over the next few decades, the estimated water pollution loads in high growth areas of Asia could be as high as 16 times for suspended solids, 17 times for total dissolved solids, and 18 times for biological pollution loading (UNESCO, 2006) .Increased pollution is not only injurious to health, lives and livelihoods of those without access to adequate safe drinking water and basic sanitation, it also damages ecosystems. In addition to damaging effects, poor quality water and unsustainable supplies can decline or limit national economic development and can also lead to adverse health and livelihood conditions. Therefore, good water and wastewater management is essential to limit pollution and minimize health risks (UNESCO, 2006). Although hydrologists have been engaged in identifying sources of pollutants and assisting reducing the pollution levels, it has already emerged as a major challenge and will likely to exacerbate in future.

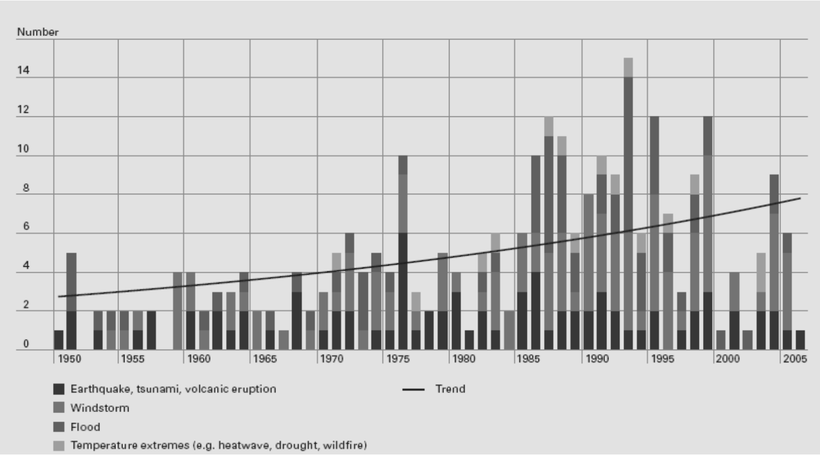

Figure 1. The number of great natural catastrophes for each year, divided according to type of event (Munich Re, 2007).

Water Scarcity and Food Security

In many parts of Asia, Africa and Latin America where millions of people go hungry everyday, there is not enough water to support irrigated agriculture. Due to increases in population and economic development, pressure on limited freshwater is mounting. UNESCO (2006) estimates that a 67 per cent increase in food crops in developing countries would be required from 2000 to 2030 to satisfy growing demand for food. However, it is optimistically projected that in the same time window a continuing rise in farm productivity levels could lower the agriculture water usage by 14 percent. In this context, there are many challenges ahead. *First*, how to increase or maintain farm productivity in rain-fed agriculture lands in a possible increase in climate variability in future? *Second*, how to make available improved seed and farm water management technology to small and marginal farmers? *Third*, how to ascertain interactions between hydrologists, agronomists and farmers at all levels of agriculture planning and implementation? *Fourth*, how can we contribute to reduce water stress while satisfying water needs of all competing sectors including agriculture?

Ecosystem and Hydrology

Everyone in the world depends on nature and ecosystem services to provide the conditions for a decent, healthy, and secure life. Hydrology and land and aquatic ecosystems are integrally interconnected. The land ecosystem influences temperature and precipitation patterns, surface-water partitioning and storage and river flows. Deforestation and replacement with grasses and shrubs in the Amazon shows a considerable reduction in evapotranspiration. This has the effect of substantially warming the surface and inhibiting convection, regional precipitation, and cloud cover (Foley *et al.,* 2007). Land-use changes effects flooding (riverine and storm surge induced), drought and ground water recharge processes. However, these processes are not completely understood. Floods and storms are an integral part of ecosystem dynamics and have both positive and negative effects on human well-being. Floods interact directly with the ecosystems of a floodplain while a storm interacts with coastal, estuarine, and desert ecosystems. Floods and storm waters bring nutrients, which are beneficial to the floodplain ecosystems (wetlands, agricultural lands, and crops, fishery, etc.) and coastal ecosystems (mangroves, mudflats, reefs, fishery, etc.). They eventually contribute to human well-being by delivering a range of ecosystem services. However, flood or flood risk management options can increase the discharge of pollutants and sediments to the coastal zones (Mirza *et al*., 2006). Water quality is another issue that is influenced by the land processes that change erosion, sedimentation, and river biogeochemistry. There are few challenges ahead for the hydrologists. *First*, how to advance knowledge and technology that will facilitate understanding of the processes involving land and aquatic ecosystems and hydrological processes? *Second*, role of floods and storms in the ecosystem dynamics and feedback processes. *Third*, advancing understanding of erosion, sedimentation and river biogeochemistry processes and their effects on aquatic ecosystems and human well-being.

Climate Change and Extremes

Hydrologists have already facing a daunting challenge beyond of accurately forecasting extreme events like floods, droughts and storm surges. Engineers, water managers and policy makers are in need of design events for infrastructures that will not compromise safety of public lives and property as well as will be economically viable. This is not a simple task at present because of persistence characteristics of hydrological events, surprises and risk transference and will be transformed into a complex one in near future due to climate change. In its recently released report, Intergovernmental Panel on Climate Change (IPCC) projected with > 90% probability of occurrence that frequency (or proportion of total rainfall from heavy falls) of heavy precipitation events increases over most areas (IPCC, 2007a). The implication is that flooding events (both magnitude and frequency) will increase in the areas/regions to be vulnerable. One example is the Asia mega-delta region (IPCC, 2007b). The IPCC (2007a) has also concluded that area to be affected by droughts will likely (> 99% probability of occurrence) increase. There are few challenges ahead. *First*, how to derive a future distribution of extreme hydrological events when it is not known? *Second*, how to reduce uncertainty in projecting a future extreme event (say flood) when transforming it from meteorology to hydrology (for example, from precipitation to peak flood)? *Third*, how to incorporate or treat uncertainties in calculating a design flood taking into account future climate change for an infrastructure?

MOVING FORWARD

Human and Ecosystem Well-Being: Central Focus

Hydrology deals with precipitation, evaporation, infiltration, groundwater flow, runoff, streamflow and the transport of dissolved or suspended substances in flowing water or in groundwater. All these are integrally connected to land and aquatic eco-systems which provide services to human-well being[8]. Hydrologists apply their knowledge to solve problems and contributing to improvement of human life (Maidment, 1992). In the emerging scenario of water complexities in this century, human and ecosystem well-being should be the central focus of hydrology.

Millennium Development Goals

In 2000, the United Nations identified eight major goals (see **Box 1**) to improve lives of billions of poor and disadvantaged people in the developing and least developed countries. By 2015, the major aims are to reduce number of poor people by half, reduction of child mortality by two-third, incidence of malaria to be halted and begin reverse the process, and bringing down proportion people without sustainable access to safe drinking water and adequate sanitation by half. However, all eight goals will continue to be pursued until 2050.

Water is the central element to fight hunger and poverty through uses in agriculture, energy and industry. Clean water provides protection from diseases and is an important factor of production in a variety of industries crucial to economic development and poverty reduction (UNDP, 2004). Hydrologists can significantly contribute to the strategies and actions programs related to many MDGs through three major concerns-water use, water control and pollution control (Figure 2).

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[8] Human well-being has multiple constituents, including basic material a good life, freedom and choice, health, good social relations, and security. Well-being is at the opposite end of a continuum from poverty, which has been defined as a “pronounced deprivation in well-being.” The constituents of well-being, as experienced and perceived by people, are situation-dependent, reflecting local geography, culture, and ecological circumstances (MEA, 2003).

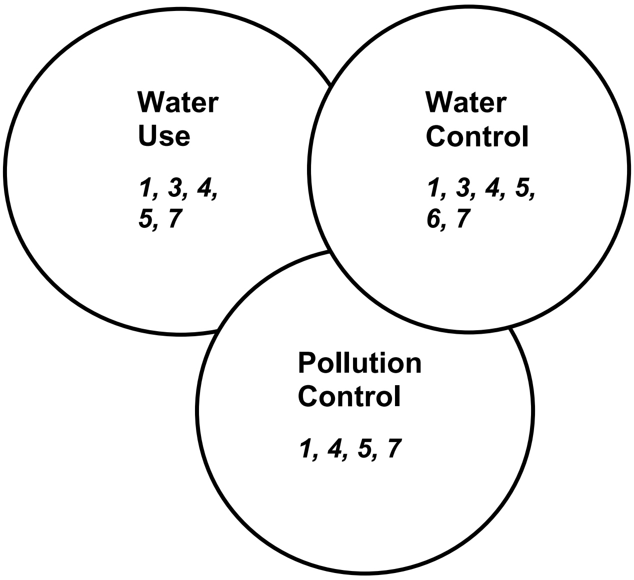

Figure 2. Major concerns of hydrologists and selected MDGs. The numbers within each circle show its relationship with the MDGs.

Box 1. The Millennium Development Goals

Goal 1: Eradicate extreme poverty and hunger
Goal 2: Achieve universal primary education
Goal 3: Promote gender equality and empower women
Goal 4: Reduce child mortality
Goal 5: Improve maternal health
Goal 6: Combat HIV/AIDS, malaria and other diseases
Goal 7: Ensure environmental sustainability
Goal 8: Develop a Global Partnership for Development

Use of Advanced Technology

Rapid development of new technologies, such as remote sensing, geographical information systems (GIS), more advanced computer hardware and software and telecommunication technology especially new-generation environmental satellites have started significantly contributing to hydrology and water resources. Hydrologists are increasingly using satellite information for flood and drought forecasting and warning. GIS interface in hydrologic models produces spatial maps which are very useful for disaster coping and mitigation. A limited use of direct feeding of satellite into hydrologic models has also started (Voisin *et al.*, 2007). However, the main challenge is huge financial and human resources that will be required to introduce such technologies, especially in developing countries.

High Definition Climate Change Scenarios

Hydrologists are becoming increasingly concerned about impacts of climate change on runoff, river flows, ground water recharge, pollutant, its sources and transportation processes, etc. Climate scenarios from the GCMs (General Circulation Models) are generally used to assess future impacts. However, the GCMs have advantages and limitations. Barrow *et al.* (2005) listed a number of advantages, which include the ability to model large-scale responses to anthropogenic forcing, long simulations can be run with different scenarios, and many variables input are readily available. Limitations are: they are computationally expensive to run, and usually have “large control run biases”. The coarse horizontal resolution of GCMs is not sufficient to resolve small scale physical processes, in specifically those related to the precipitation regime which is particularly a concern for hydrologists. For many economic sectors (water, energy, etc.), scenarios of finer resolutions are required for vulnerability, impacts and adaptation assessments. Two alternative methods are in use to construct high resolution climate scenarios. They are: statistical downscaling and dynamical downscaling. Statistical downscaling assumes that regional or local climate is conditioned by the large-scale climate state and regional/local physiographic features. Dynamical downscaling refers to climate scenarios derived from the high resolution regional climate model (RCM) which usually uses low resolution GCM fields to provide time-dependent lateral boundary conditions. In doing so, uncertainties inherent in the GCM scenarios are propagated to the RCM scenarios. If the scenarios are used in hydrologic models, the magnitude of uncertainty increases. The key challenge for the hydrologists is to develop method(s) to reduce uncertainty in climate change scenarios as well as in simulated hydrologic outputs.

Facilitating Climate Change Adaptation

The science of adaptation has significantly developed in the last decade and a half. Adaptation[9] measures and processes are well-researched in the natural hazards science since 1960s. However, this has become an important issue in tackling climate change induced vulnerability and impacts. The IPCC (2007b) has concluded that a wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to future climate change. As water would be one of the most impacted sectors in future due to climate change and sea level rise, hydrologists can play a major role in identifying adaptation measures, facilitating adaptation process and strengthening adaptive capacity in the society.

Integration with other Disciplines

"…Traditionally, hydrologists have practiced their profession by specializing in hydrology but maintaining their primary affiliation with another discipline in engineering or applied science. In recent years, however, hydrology has become increasingly recognized as an ***independent profession*** (Maidment, 1992; p.1.2)." However, hydrologists need to be out of this individualism because there is a greater need of integration with multi-disciplinary professions to serve society better and to contribute to human and ecosystem well-being. The major challenge will be to craft strategies to integrate the profession with other disciplines which include: climatology and meteorology, soil science, geomorphology, economics, agriculture, toxicology, biology, botany, engineering, fluid mechanics, etc.

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[9] **Adaptation -** Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation (IPCC, 2001)

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Climatic Change - Consequences for the Nord Pool power system

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Keywords: Electricity production, Climate change, Nord Pool

ABSTRACT

This paper describes simulations of the present Nord Pool power system with climate conditions given by the historical years 1961 to 1990 (the Reference case) and comparing with simulations given by the HadAM-B2 and ECHAM-B2 future climate scenarios. The future climate scenarios refer to the period 2071-2100. The simulated climate scenarios show a substantial increase in hydro production in Sweden, Finland and Norway, especially for the ECHAM-B2 scenario. Virtually the whole increase in inflow comes in the winter season; most areas actually have a decline in summer inflow. While being a net importer of electricity in the Reference case, the Nord Pool area would be a net exporter with the inflows given by the ECHAM scenario.

INTRODUCTION

The objective of the simulations is to quantify changes in generation and demand of electricity as a result of climate change. The documented study is a part of the Nordic research project on Climate and Energy (http://www.os.is/ce) with funding from the Nordic Energy Research.

The approach used is to simulate a given system configuration with present and changed climate conditions respectively. The results thus reflect how the generation and demand characteristics of a fixed system configuration change for assumed changes in precipitation, temperatures and wind speed, and how this influences other quantities like exchanges with continental Europe.

We use the electricity system in 2010 in the simulations because this system can be forecasted with reasonable accuracy. For this stage, assumptions must be made about demand and generation and transmission capacities, which can be based on existing forecasts and known plans. Moreover, assumptions must be made on thermal generation costs and exchange prices with continental Europe.

The simulation of the system is done by the EMPS-model. A more detailed description of the EMPS model is given in *Mo et al. (2006)*. A mathematical description of the model with focus on economical interpretation is given in *Wolfgang et al.* (2005). The EMPS-model is applied by most of the major players in the Nord Pool market.

The EMPS model simulates the balance between supply and demand in a geographically distributed electricity market for a selection of historical weather years, which represent hydrology, temperature and wind speed variations. The hydrology affects hydropower generation, temperature affects the load and the wind speed relates to the generation from windmills.

METHOD

The basic input to the simulations of the Nord Pool market (Sweden, Norway, Finland and Denmark) exists of time series for inflow, wind and temperature. The future climate scenarios are generated by the HadAM3H and ECHAM/OPYC3 global climate models, denoted HadAm-B2 and ECHAM-B2 respectively. The scenarios from the global climate models have been further refined and processed by regional climate models and hydrological models, see *Fenger (2007)* for an overview of the whole process.

Simulations with the EMPS model consist of two phases. In the first "strategy" phase, so called water values for the hydro reservoirs are calculated. In essence, these give the marginal resource cost of the water in the reservoir as a function of the reservoir level and the time of the year. In the "simulation" phase, the water values are used to simulate an optimal dispatch of the system, taking into account the costs of thermal generation, imports, exports and flexible demand options. Transmission constraints between areas are taken into account, and exchanges with countries outside the Nord Pool area are also modeled. A model with 23 separate areas for the Nord Pool system was used, reflecting the major transmission constraints and hydrological diversity. The basic time step for the simulations is one week, which is subdivided in seven periods to describe the variation of demand within the week. Reported values reflect the average of the 30 simulated historical weather years.

Inflow data are input to the hydro reservoirs in the EMPS model. Changes in inflow will directly influence the simulated generation from the hydro plants, but a change in inflow is not necessarily matched by a corresponding change in generation, because there will also be changes in spillage and the timing of the generation. Wind data are input to the calculation of wind generation. Because wind cannot be stored, changes in wind speed are directly reflected by changes in wind generation, apart from limitations caused by maximum wind speed. Temperature data are used to calculate demand in the model. Because there is a significant use of electricity for heating purposes, demand depends on temperatures. Changes in temperatures will therefore result in changes in demand. The use of air conditioning is not modeled, and a potential increase of demand caused by increased use of air conditioning in summer due to higher temperatures is therefore not taken into account.

All simulations are done on a fixed system configuration. Increased hydro and wind generation combined with lower demand for heating purposes lead to lower prices. However, demand also depend on prices, therefore the reduction in demand caused by higher winter temperatures is partly offset by an increase caused by lower prices.

DATA DESCRIPTION

Electricity demand is based on recent forecasts for the Nordic countries for 2010: Sweden: 156.0 TWh, Norway: 130.3 TWh, Finland: 96.4 TWh, Denmark: 39.3 TWh. These estimates include all network losses. Installed generation capacity is based on Nordel statistics as of 31 December 2004, corrected for known and expected changes, see Table 1.

Interconnection capacities were modeled with their present capacities, modified for expected and known changes before 2010. These include an increase of 600 MW of the interconnection between Finland and Sweden (Fenno-Skan 2) and of the 600 MW interconnection between Denmark and Norway (Skagerakk IV), as well as new interconnections between East and West Denmark (600 MW) and Norway and the Netherlands (700 MW).

Water values, system dispatch and economic calculations in the model depend on the cost assumptions that are made. A crucial parameter for all energy costs is the expected oil price. Although oil prices recently have fluctuated between 60 and 70 USD/barrel, long term projections by the IMF suggest a level of 36 USD/barrel (IMF, 2005, Chapter IV). This is roughly equal to the average oil price in 2004, 38 USD/barrel. Fuel price estimates were therefore based on average 2004 oil and coal prices. Also prices for exchange with Germany, Poland and the Netherlands were based on 2004 prices for the power exchanges in Germany and the Netherlands. CO2 emission quota costs were not taken into account.

Table 1 . Assumed installed capacity in the Nord Pool area in 2010

	Denmark	Finland	Norway	Sweden	Nord Pool
Installed capacity 1)	13 530	18 788	30 693	35 297	98 308
Thermal power	8 728	12 794	551	16 320	38 393
• Nuclear	-	4 271	-	10 167	14 438
• other thermal 2)	8 728	8 523	551	6 153	23 955
o condense and CHP district heating	8 077	6 627	438	4 038	19 180
o CHP industry	381	996	49	492	1 918
o gas turbines etc	270	900	64	1 623	2 857
Renewable energy	4 802	5 994	30 142	18 977	59 915
• hydro power	11	2 986	28 928	16 137	48 062
• other renewable	4 791	3 008	1 214	2 840	11 853
o wind	4 102	499	1 200	1 142	6 943
o biomass	418	2 378	96	1 545	4 437
o waste	271	131	27	153	582

1) Sum of installed capacity in all units. This is considerably higher than available capacity at any given instant

2) Fossil fuels like coal, oil and gas

RESULTS

Table 2 shows simulated regional inflow to the Nord Pool area for three different cases (Reference and the two climate scenarios).

Table 2. Regional inflow, average values (TWh*)*

	Reference			HadAM			ECHAM		
Area	winter	summer	year	winter	summer	year	winter	summer	year
East Norway	9.2	44.2	53.3	15.5	35.1	50.6	18.8	31.9	50.8
West Norway	5.7	32.2	37.9	13.9	31.2	45.1	23.5	36.2	59.7
Central Norway	2.8	11.1	13.9	4.6	8.1	12.6	7.2	9.0	16.2
North Norway	2.9	15.9	18.8	6.7	12.2	18.9	10.5	15.0	25.5
Sum Norway	20.6	103.4	124.0	40.7	86.6	127.3	60.0	92.2	152.2
North Sweden	6.5	41.7	48.2	12.6	39.5	52.1	19.0	42.0	60.9
Central Sweden	2.7	8.6	11.3	4.7	7.9	12.6	6.3	6.9	13.1
South Sweden	3.2	3.2	6.4	4.2	2.4	6.6	5.2	2.3	7.5
Sum Sweden	12.5	53.5	65.9	21.5	49.8	71.4	30.4	51.2	81.6
North Finland	3.8	4.6	8.4	5.3	4.5	9.8	6.6	5.0	11.6
South Finland	2.6	2.9	5.5	3.1	2.6	5.7	3.9	3.0	6.9
Sum Finland	6.3	7.5	13.9	8.4	7.1	15.5	10.5	8.0	18.5

Sum Nord Pool area	39.5	164.4	203.8	70.6	143.5	214.1	100.9	151.4	252.3

Total annual inflow to the Nord Pool area in 2010 is 204 TWh for the simulation period 1961-1990 in the Reference scenario. With the inflow given by the HadAM scenario, the inflow to the same hydro power generation system would increase to 214 TWh (+5.0 %). The corresponding number for the ECHAM scenario is 252 TWh (+23.8 %). In the HadAm scenario the largest increase is in Sweden with 5.6 TWh, and the major share of this comes from North Sweden. In the ECHAM scenario, the largest absolute increase is in Norway (28.2 TWh). 22 TWh of this increase comes in West Norway. Finland has the smallest absolute increase because it has the smallest system, but the relative increase is largest in Finland with 33 %. The whole increase occurs in the winter season – in fact a considerable decrease in summer inflow is expected for both scenarios, with the exception of Finland in the ECHAM scenario. In Norway the main increase occurs in Western Norway. For Sweden, both relative and absolute changes are largest in the North, with a 191 % increase in winter inflow in the ECHAM scenario. Especially South Sweden has a significant relative decrease in summer inflow (24 and 27 %). In Finland, the expected changes are generally larger in the North than in the South. Also for Finland the major increases occur in the winter season (+75 % for Northern Finland in the ECHAM scenario), but in Finland the winter increase is generally less than in Norway and Sweden.

Total hydro generation increases with 34 TWh in the ECHAM scenario, considerably less than inflow, indicating a significant increase in overflow see Table 3 and Table 4. In the HadAm scenario, the largest increase occurs in Sweden (4 TWh), while Norway has the largest increase in the ECHAM scenario (20 TWh). The respective changes in the winter and summer generation shares of total generation are quite small compared with the changes in inflow. This is a natural result of the fact that generation to a large degree must follow demand, the profile of which is not assumed to change significantly.

Table 3. Simulated hydro generation (TWh)

	Reference			HadAM			ECHAM		
Area	winter	summer	year	winter	summer	year	winter	summer	Year
Norway	67.4	47.9	115.3	68.6	49.4	117.9	75.8	59.2	135.0
Sweden	34.2	28.1	62.3	34.8	31.5	66.3	39.2	35.3	74.5
Finland	6.2	5.7	11.9	7.1	5.6	12.8	7.8	6.3	14.1
Sum Nord Pool area	107.7	81.8	189.5	110.5	86.5	197.0	122.8	100.8	223.6

Table 4. Simulated spillage (TWh)

	Reference			HadAM			ECHAM		
Area	winter	summer	year	Winter	summer	year	winter	Summer	year
Norway	0.8	7.4	8.1	3.1	5.6	8.7	7.5	9.1	16.5
Sweden	0.7	2.6	3.3	1.6	3.1	4.7	2.8	3.9	6.8
Finland	0.7	1.2	1.9	1.5	1.2	2.7	2.6	1.8	4.4
Sum Nord Pool area	2.2	11.2	13.4	6.2	9.9	16.1	12.9	14.8	27.7

The simulation results show only minor changes in wind generation. The average yearly wind production is 25.9 TWh for the Nord Pool area. There is a small shift towards more winter generation in the ECHAM scenario.

Table 5 shows simulated thermal generation for each country. In the reference scenario, simulated thermal generation in the area is 198 TWh. Due to more hydro production this is reduced with 8 TWh in the HadAM scenario, and with almost 25 TWh to 173.7 TWh in the ECHAM scenario. The major share of the reduction in thermal generation is in Finland. This is the result of the assumptions on generation costs that have been made. The reduction in thermal generation is evenly distributed between the winter and summer seasons. Total demand is 423 TWh in the Reference scenario and 414 TWh in both the HadAm and ECHAM scenarios. Temperatures are slightly higher in the latter scenario, but the effect on demand is offset by lower prices.

Table 5. Simulated thermal generation (TWh)

	Reference			HadAM			ECHAM		
Area	winter	summer	year	winter	Summer	year	winter	Summer	year
Norway	2.5	2.2	4.7	2.4	2.0	4.4	2.0	1.7	3.7
Sweden	45.3	36.4	81.7	44.9	35.7	80.7	42.9	33.6	76.5
Denmark	20.5	22.2	42.7	20.0	21.2	41.2	18.7	18.8	37.5
Finland	37.5	31.7	69.2	34.7	29.5	64.2	30.2	25.8	56.0
Sum Nord Pool area	105.7	92.6	198.3	102.0	88.5	190.5	93.8	79.9	173.7

Finally, Table 6 shows each country's resulting balance, including net import.

Table 6. Energy balance for each county (TWh)

Reference	Hydro	Thermal	Wind	Net import	Demand
Norway	115.3	4.7	4.1	6.7	130.7
Sweden	62.3	81.7	3.8	11.6	159.5
Denmark	0.0	42.7	15.7	-19.0	39.4
Finland	11.9	69.2	1.6	13.8	96.5
Nord Pool area	189.5	198.3	25.1	13.2	426.1

HadAM	Hydro	Thermal	Wind	Net import	Demand
Norway	117.9	4.4	4.1	1.6	128.0
Sweden	66.3	80.7	4.1	4.8	155.8
Denmark	0.0	41.2	16.3	-18.0	39.5
Finland	12.8	64.2	1.4	15.2	93.6
Nord Pool area	197.0	190.5	25.9	3.5	416.8

ECHAM	Hydro	Thermal	Wind	Net import	Demand
Norway	135.0	3.7	4.3	-16.2	126.8
Sweden	74.5	76.5	3.9	1.7	156.5
Denmark	0.0	37.5	16.2	-14.0	39.6
Finland	14.1	56.0	1.5	22.8	94.4
Nord Pool area	223.6	173.7	25.9	-5.8	417.3

Denmark is a large exporter for all scenarios. This reflects both the balance between demand and supply in the other countries and the price assumptions that have been made as well as the large amount of wind power in Denmark. If higher costs had been assumed in Denmark and/or lower costs for the alternatives, Denmark would have exported less, although still considerably because of the amount of wind power. The important results of this analysis are related to the changes in the energy balance in the Nord Pool area caused by climate change. Finland is the largest importer in all scenarios. 10.5 TWh comes from Russia on contracts that are assumed not to depend on the market situation. The reason for increased import to Finland is that more hydro power becomes available in Norway and

Sweden, and this is transported to the country with the highest generation costs on the margin, Finland. Sweden imports 11.6 TWh in the reference case, 4.8 TWh in the HadAM scenario and only 1.7 TWh in the ECHAM scenario. The biggest changes occur for Norway, caused by the large increases in hydro generation, especially in the ECHAM scenario. From importing 6.7 TWh in the reference case, Norway exports 16.2 TWh in the ECHAM scenario.

CONCLUSIONS

The most significant effect of climate change on the power sector is an increase in hydro generation, which is considerable in the ECHAM-B2 scenario. Under present climate conditions, total inflow in a normal year in the Nord Pool area is 204 TWh. With the HadAM-B2 scenario, this increases to 214 TWh (+5.0 %), and with the ECHAM-B2 scenario to 252 TWh (+23.8 %). Hydro generation increases for all countries Sweden, Norway and Finland, but in East Norway inflow is reduced for both scenarios and in Central Norway for the HadAm-B2 scenario. Virtually the whole increase in inflow comes in the winter season; most areas actually have a decline in summer inflow.

As a result of increased inflow there is also an increase in hydro generation. However, the increase in generation is less than the increase in inflow due to an increase in spillage, especially in the ECHAM-B2 scenario. Hydro generation increases from 190 TWh with present conditions to 197 TWh (+4.0 %) in the HadAM-B2 scenario and 224 TWh (+18.0 %) in the ECHAM-B2 scenario.

Wind generation does not change much with climate change. With present conditions, a total of 25.1 TWh is produced, increasing to 25.9 TWh in both climate scenarios. In the HadAM-B2 scenario, this increase is evenly distributed between summer and winter, while it occurs mainly in winter in the ECHAM-B2 scenario.

Climate change will also have an impact on demand through increased temperatures. Because electricity to a considerable extent is used for heating purposes, especially in Norway, an increase in average winter temperatures will reduce demand. To some extent, this decrease in demand is counteracted by lower prices, which lead to increased demand. The net effect is that demand drops from 423 TWh in the reference case to 414 TWh in both climate scenarios.

Summing up, climate change leads to a considerable increase in hydro generation during winter as well as reduced demand for heating. In total the energy balance for the Nord Pool area is improved with 43.8 TWh (23 %) for the ECHAM scenario. As a result, thermal generation and imports in the Nord Pool area are reduced, and import turns to net export of electricity. All effects are strongest for the ECHAM-B2 scenario.

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Climate Change and Flooding: Mapping Vulnerability in the City of London, Upper Thames River Basin, Canada

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ABSTRACT

A study was undertaken in the Upper Thames River Basin in Canada to assess the risk of and vulnerability to flood (and drought) under present and future climatic conditions. A *K*-nearest-neighbor (*K*-NN) non-parametric weather generator was developed and used to produce two climate change scenarios. Daily observations of maximum and minimum temperature, and precipitation from stations in the watershed were perturbed and shuffled (guided by global climate model (GCM) input) to create climate scenarios. These data were used as input to a semi-distributed event-based rainfall-runoff model. For the flooding assessment, precipitation events representing annual maximum daily rainfall were input to the hydrologic model to determine the corresponding peak flows. A frequency analysis was performed on the peak flows and return periods determined. A hydraulic model was used to convert flood flow into water elevation for floodplain mapping of an urbanized area of London, Ontario located in the Upper Thames watershed. First, a traditional hazard mapping analysis was conducted in a geographic information system (GIS) to determine the hazard associated with the 1 in 100-, 250- and 500-year floods under historic and two climate change scenarios. Changes in the area affected by the floodlines were calculated, along with estimates of the number of structures affected using overlay techniques in GIS. Second, vulnerability indices were developed to determine the vulnerability of the population, in terms of their "adaptive capacity" or ability to respond to or cope with floods. Socio-economic factors and physical factors (housing type and age) from the 2001 Canada Census Data were used to develop indices. Indices maps were created for each factor and combined to create a total socio-economic vulnerability index for each dissemination area. The resulting output identifies areas of vulnerable populations, which can help improve flood planning in the watershed. Project details can be found at http://www.eng.uwo.ca/research/iclr/fids/cfcas-climate.html.

INTRODUCTION

Extreme events or natural hazards such as floods, droughts, and windstorms are acute examples where climate and socio-economic systems interact resulting in lives lost, economic damages, and disruption of lives and infrastructure. The vulnerability profile of a system or community is dependent on the hazard or external environmental conditions as well as the characteristics of social groups that affect their response capacity, attributes of the biophysical system that affect susceptibility or sensitivity, and external human system factors (e.g., policies, institutions) (Füssel, 2007). Assessing vulnerability or in broad terms exploring the potential for loss, informs society on who and what are exposed to a natural hazard, and in turn offers insight on the capacity to cope with or adapt to the hazard and where policy and structural responses might be necessary to prevent damage or disaster. Flooding is the most common natural hazard affecting Canada today, and it is also the most costly in terms of property damage (PSEPF, 2005; ICLR, 2007). Numerous studies have addressed contemporary vulnerability of Canadian communities to flooding hazard but virtually none explores the effect of climate change on precipitation intensity and flooding hazard (Cunderlik & Simonovic, 2005; Roy *et al.*, 2001), and following from that vulnerability and the capacity to cope or adapt. Human-caused climate change, from increasing concentrations of greenhouse gases, is very likely to increase the intensity of precipitation enhancing the potential risk of flash flooding and urban flooding, and increasing the exposure of systems and communities to this hazard (Meehl *et al.*, 2007).

This paper presents the vulnerability assessment component of the research project, "Assessment of Water Resources Risk and Vulnerability to Changing Climatic Conditions" whose main objectives were to develop water resources risk and vulnerability assessment tools, assess climatic vulnerability of the Upper Thames River basin, and recommend guidelines for vulnerability reduction and hazard mitigation in order to improve the understanding of the processes leading to hydrological hazards, including floods and drought.

The Upper Thames River watershed, located in south-western Ontario, covers an area of 3,432 km^2 with the dominant land use agriculture (78%) and nine per cent urban. The watershed has a population over 420,000 people (UTRCA, 2006) with most living in the City of London. This study focuses on the Forks of the Thames, which is the confluence of the north and south branches of the Thames River near the centre of the City of London. Historically, this area has experienced flooding and associated damages.

METHODS

The vulnerability assessment component described herein builds upon the climate change scenario-generating techniques and hydrologic modelling developed in this research project and explores the changing flooding hazard due to climate change. These methods are described briefly as well as the data collection and development of the indices and the mapping to assess vulnerability.

A modified *K*-nearest-neighbor (*K*-NN) non-parametric weather generator was developed and used to produce two climate change scenarios which were used for the vulnerability assessment – dry/warm for drought analysis and wet for flooding assessment (Sharif & Burn, 2006a, 2006b). The method develops weather sequences by resampling historical data (daily maximum and minimum temperature, precipitation) in the watershed with perturbations from Global Climate Models (GCMs) while preserving the prominent statistical characteristics. A key improvement in the scenario-generating technique is that the downscaled data produced for the watershed are spatially correlated as the same day's weather is adopted as the weather for all stations. Days with daily precipitation 25 mm or more were disaggregated to hourly values (Wey, 2006) for input to a hydrologic rainfall-runoff model.

A semi-distributed event-based rainfall-runoff model (based on HEC-HMS) was developed for this project and is described by Cunderlik & Simonovic (2004, 2007). The drought modelling is described in Prodanovic & Simonovic, 2006a. For the flooding assessment, precipitation events representing annual maximum daily rainfall were input to the hydrologic model to determine the corresponding peak flows (Prodanovic & Simonovic, 2006b). A large number of event storms were run in the hydrologic model, so that a flow frequency analysis could be performed and return periods determined. A hydraulic model was used to convert flood flow into water elevation for floodplain mapping of the Forks of the Thames River area.

The 1 in 100-, 250- and 500-year floods were used in the vulnerability assessment. For planning in the Upper Thames River watershed, the 100-year flood is used to separate the flood fringe from the floodway and the 250-year flood defines the flood plain or hazard area. The 500-year floodline coincided with flood damage estimation work completed by the Upper Thames River Conservation Authority for this project and represents the most extreme condition used for disaster planning (personal communication, M. Helsten, 2006).

The areas of the 1 in 100, 250- and 500-year floodlines for all climate scenarios were calculated, and area changes in the floodline between scenarios were determined. The floodlines were then overlaid with layers representing the location of homes and buildings to determine the number that would be affected by each floodline.

The vulnerability assessment approach is place-based and examines the changing exposure to riverine flooding in an urban area due to climate change scenarios, and the socio-economic and physical attributes of the place that influence the capacity to cope or ability to adapt to flooding by undertaking proactive flood-proofing actions prior to an event, responding during the flooding emergency, and recovering after a flooding event. Three thematic areas were defined for vulnerability indicator development and included: ability to cope and respond, differential access to resources, and level of situational exposure. Ten variables from the Canadian Census 2001 Profile Tables at the dissemination area level were used (Statistics Canada, 2003). The variables chosen were based on a review of existing literature assessing vulnerability to current hazards (Cutter *et al.*, 2000; Montz & Evans, 2001; Chakraborty *et al.*, 2005; Phillips *et al.*, 2005; Rygel *et al.*, 2006) and a changing climate (Wu *et al.*, 2002). The contribution of each indicator to vulnerability and the thematic groupings are outlined in Table 2.

Table 1. Indicators selected for the Upper Thames vulnerability analysis.

Indicators	**Rational for contribution to vulnerability**
Ability to Cope and Respond: characteristics that affect populations ability to cope and respond to flooding	
Over 65 years of age	• Limited mobility (physical difficulties in evacuation); reluctant to leave homes; health-related problems, longer recovery (Health Canada, 2001; Rygel *et al.*, 2006)
Under 19 years of age	• Young children, in particular, physically weak; physical and mental health-related problems; less mobile (Health Canada, 2001); legally dependent until age of 18
No Knowledge of Official Languages	• Language barrier; may not understand danger or respond appropriately; may not understand home preparedness preventative measures
Females	• Physically disadvantaged in evacuation or home preparedness; increased emotion, work, stress, physical domestic labour; slower to recover (Rex, 1999)
Differential Access to Resources: economic characteristics that affect populations access to resources in order to respond	
Low Income Households (spend more than 54% of their income on food, shelter and clothing)	• Limited resources to prepare or respond (i.e. lack communication devices to stay informed, have fewer social or community contacts; rely on public resources) (Phillips *et al.*, 2006)
Single Parent Families	• Limited resources to prepare or respond
Rely on Public Transit	• May lack mobility
Renters	• Landlords lax on disaster preparedness or cleanup (Rex, 1999) • Limited resources and motivation to prepare or respond; less informed, fewer contacts
Level of Situational Exposure: structural integrity of homes; likelihood of potential damage or failure	
Housing Type (single detached, semi-detached, row houses, detached duplexes, other single detached homes; mobile or moveable dwellings)	• Low structures (i.e. one or two storey homes) are more susceptible to damage from flooding than apartments (Messner & Meyer, 2005)
Period of Construction (pre-1970)	• Older homes may be constructed in floodplains; regulation not in effect until 1961 (high water mark) and 1973 (regional storm level i.e. 250-year flood line) (personal communication, M. Helsten, 2006) • Older neighbourhoods have ageing infrastructure which may be more susceptible to flooding (e.g., water and sewer systems; dykes, dams, etc.)

The ten indicators were standardized (from 0.0 to 1.0) by dividing the value for each dissemination area by the maximum value of the variable for all dissemination areas in the study area; higher values indicate greater vulnerability. Vulnerability scores, one for each vulnerability thematic area, were calculated by averaging the standardized vulnerability scores from the appropriate groupings of individual indicators. A total vulnerability score was computed by summing the three individual thematic scores (maximum value of 3.0) and mapped into quintiles (low (≤20th percentile), medium (41-60th percentile) and high (81-100th percentile)) in a GIS.

RESULTS

For this assessment, the climate change scenarios were specifically developed to explore the impacts of extremes – wetter conditions with more intense precipitation events, and warmer, drier conditions with more frequent drought. In the traditional hazards approach to vulnerability assessment, exposure to the physical hazard is described as the distribution of the hazardous condition and the people and structures affected. In this community, exposure to flooding hazard increases under the wet climate change scenario (Table 2). The modelled 100-, 250- and 500-year floodlines for the wet climate change scenario are presented in Figure 1. For total area affected, the 250-year floodline area includes the 100-year floodline area while the 500-year floodline includes both the 100- and 250-year floodline areas. This approach describes the hazard exposure; however, it does not assess or differentiate the coping/adaptation capabilities of the population exposed to the flooding hazard. Using vulnerability indicators and mapping them allows for the analysis of the distribution of coping/adaptive within the community. In Figure 2, the total vulnerability index (aggregated total vulnerability consisting of ability to cope and respond, differential access to resources, and level of situational exposure) per dissemination area is presented. The 250-year floodline is shown as it is used as the basis for watershed floodplain planning. Mapping shows that vulnerability to flooding is not evenly distributed throughout the Forks of the Thames River region and "hot spots" emerge that would benefit from additional planning and management attention in order to identify means to reduce flooding vulnerability.

Table 2. Modelled flooded area under historic conditions and two climate scenarios (wet for flooding and dry for drought conditions) and number of homes (all private homes/apartments, etc.) and buildings (commercial, institutional, industrial, etc.) affected.

Floodline	Climate Scenario	Area (m^2)	Change in Area	Change in Percent	No. Homes Flooded	No. Buildings Flooded
100-year	Historic	5,291,440			1,141	34
	Dry	3,930,436	-1,361,004	-25.7%	68	18
	Wet	5,595,988	+ 304,548	+ 5.8%	1,249	42
250-year	Historic	5,858,976			1,376	58
	Dry	5,101,848	-757,128	-12.9%	1,059	33
	Wet	6,116,988	+258,012	+ 4.4%	1,486	59
500-year	Historic	6,268,729			1,560	71
	Dry	5,362,852	-905,877	-14.5%	1,155	36
	Wet	6,567,292	+298,563	+ 4.8%	1,690	83

DISCUSSION AND CONCLUSIONS

The dissemination areas with the highest total vulnerability scores or the "hot spots" are circled in Figure 2. The factor contributing greatest to vulnerability was the "level of situational exposure" indicator (high-medium to high) which identified older areas in the community where houses were built before floodplain restrictions were implemented. "Differential access to resources" indictor (medium to high) was the next contributor to vulnerability. The indicator provides information on dissemination areas with low income households that would not have the economic resources to invest in adaptation. Dissemination areas with a high proportion of renters would indicate an area where it is more likely that preventative measures would not be undertaken because renters and landlords are less likely to be motivated to invest in prevention and subsequent rebuilding and retrofitting as owner occupied areas. "Ability to cope and respond" indictor (low-medium) had the lowest impact on the total vulnerability score. This indicator identifies members of the community that are likely to have more challenges addressing pre-event vulnerability reduction, emergency response and post-event recovery because of age, physical capabilities, language barriers or time availability.

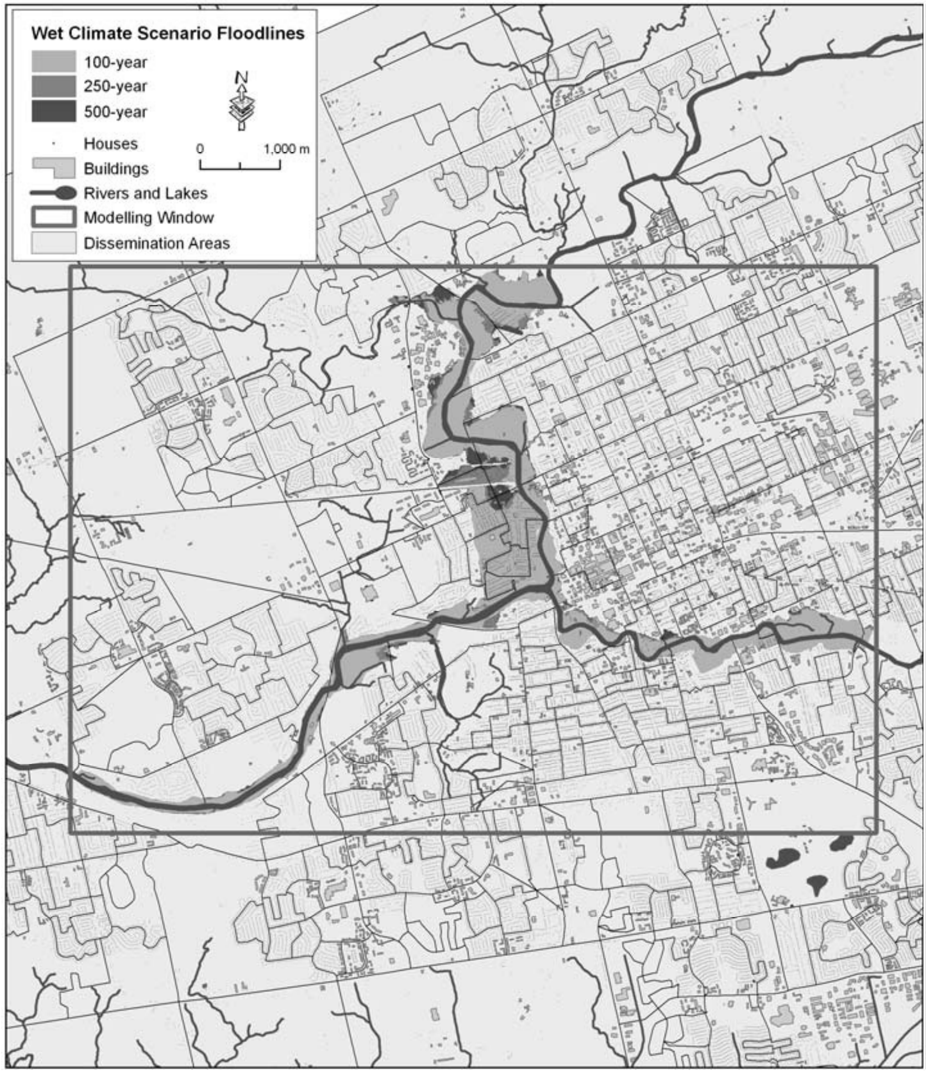

Figure 1. Modelled floodlines for the wet climate change scenario

Figure 2. Total vulnerability mapping illustrating “hot spot” areas

The study shows that there is increasing risk from flooding events with the wet climate change scenario that needs to be considered in municipal and watershed planning in the Upper Thames River watershed. The vulnerability approach that builds upon traditional methods (e.g., describing how the flooding hazard changes) enhances the information provided for planning and management by including socio-economic and physical factors that affect the community and the capacity to cope with or adapt to the hazard – flooding – in a proactive pre-event hazard/disaster prevention, emergency response and subsequent cleanup. Feedback is needed from the stakeholder community on the usefulness of these data and maps and will be solicited through a stakeholder meeting.

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Possible impacts of climate change on groundwater resources and groundwater flow in well developed water bearing aquifers

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ABSTRACT

Bilan model (developed by T.G. Masaryk Water Research Institute in Prague for basin water balance simulation in monthly step) was applied in combination with Modflow model (modular three-dimensional finite-difference groundwater flow model developed by the United States Geological Survey) for estimation of possible impacts of climate change on groundwater resources in the Metuje River basin, which is a part of an important hydrogeological region (Cretaceous geological formation characterised by deep circulation of groundwater and its high storage) in the Czech Republic.

Parameters of Bilan model were calibrated for input meteorological series (precipitation, air temperature and relative air humidity) from the period 1974-2004. The monthly groundwater recharge series simulated for this period was used for Modflow simulation of conditions that are not affected by climate change (in fact the end of this period is already probably affected). Subsequent simulation by the Bilan and Modflow models for the affected conditions was based on the input meteorological series that had been modified according to a selected climate change scenario and on the parameters of the models that were calibrated in the previous step.

Results of a comparison of Modflow simulations for not affected and affected recharge series showed that consequently to the climate change the groundwater levels in the basin could decrease by as much as 10 meters. The base flow could drop to levels of the existing groundwater abstractions in the basin (about 100 $l\ s^{-1}$) and therefore the Metuje River would fully dry in the periods when it is normally almost exclusively fed from the groundwater storage.

INTRODUCTION

The first study in the Czech Republic that was focused on examination of climate change impacts on water regime by simulating water balance components was probably carried out by T.G. Masaryk Water Research Institute (T.G.M. WRI) in 1992. This study (Kašpárek et al., 1992) used BILAN water balance model (its version from 1992) and incremental climate change scenarios for simulation of the monthly runoff from the basin of the Metuje River at Teplice n. M.

During 1995-1996, the climate change studies (climate change scenarios from 1989-1992 based on global circulation models) were focused on participation of the Czech Republic in the US Country studies programme (Hladný et al., 1996). This research continued in an EU project on Impacts of climate change on hydrological regimes and water resources in Europe, whose results are reviewed in Kašpárek, L. (1998).

In the flowing period, the studies of climate change impacts on water regime and water resources in the Czech Republic were based on new generation of GCM climate change scenarios (Nakicenovic et al., 2000), which were derived for the Czech Republic by Faculty of Mathematics and Physics of Charles University.

Most of the results from those studies that were carried out by water balance modelling during the period 1992-2005 were reviewed in Chapter 4 of Kašpárek, L., Novický, O. and Peláková (2006). Chapter 2 of this collection describes results of water balance simulation for the Metuje River basin (by using Bilan model) and indicates that causal factors of extreme drought in 2004 include a decrease in groundwater storage.

Modflow model was applied for simulation of groundwater conditions in the Metuje River basin in a Czech-Polish co-operation, whose results from the period 1975-2004 are described in Kašpárek, et al. (2006). Conclusions from this report suggest that hydrological drought and possible impacts of climate change on groundwater resources and groundwater flow could be suitably analysed by a linked application of the hydrological model (Bilan) and the hydraulic model (Modflow).

This idea was implemented in 2006 by T.G.M. WRI in a hydrological component of a project on Research and protection of hydrosphere – research of relationships and processes in water component of the environment focused on impacts of human pressures, the sustainable use and protection of the hydrosphere and legislative tools (research and development project sponsored by the Czech government). The results of this application and of the related studies are summarized in the paper and described in more detail in Novický, O. et al. (2006).

METHODS

Bilan hydrological model is described in Tallaksen and Lannen (2004) and its executable version is available together with example data for its application on a CD, which is attached to the textbook. Input data of Bilan model include primarily time series of monthly precipitation, temperature and relative air humidity. The model simulates time series of monthly potential evapotranspiration, actual evapotranspiration, infiltration across the land surface and recharge from the soil to the aquifer. The output of the model includes monthly series of water storages in the snow pack, soil and aquifer. All these hydrological variables apply to the whole catchment. Furthermore, three runoff components, i.e. surface runoff, interflow and base flow (groundwater discharge) are calculated at the outlet of the catchment. The eight free parameters of the Bilan model are calibrated on the basis of minimising the differences between simulated and observed outflow from the basin.

The monthly groundwater recharge series simulated for affected and not affected climate conditions by Bilan model were used as an input for Modflow simulation. The geological layers in the Metuje River basin form combination of confined and unconfined aquifers and Modflow model, which can be used for simulation of steady and unsteady flow in a flow system in which aquifer layers can be confined, unconfined or combined, was suitable hydraulic model for the basin. The hydraulic model was used for simulation of spatial distribution of groundwater levels and base flow and its parameters were calibrated by minimising differences between the observed and simulated groundwater levels and also between simulated base flow (by Bilan model) and base flow derived from streamflow hydrographs.

The climate change scenarios were based on HadCM2 (Johns, 1997) or ECHAM4 (Roeckner et al., 1996) GCM simulations applying transient warm start with dynamic ocean experiments, SRES CO_2 emission scenarios (A2 scenario as pessimistic alternative and B1 scenario as optimistic alternative) developed by Nakicenovic et al. (2000) and alternatively low (1.5 °C) and high (4.5 °C) climate sensitivity to CO_2 concentration (climate sensitivity refers to the equilibrium change in global mean surface temperature following a doubling of the atmospheric CO_2 concentration).

STUDY BASIN AND DATA

The basin of the Metuje River (a tributary of the Elbe River with basin area of 240 km^2) is predominantly located in Northern Bohemia (Czech Republic, see Figure 1) with a small part in Poland. Its landscape is characterized by a high diversity of deep valleys, gentle and steep slopes and uplands. The catchment is filled with Mesozoic (Triassic and Cretaceous) deposits overlying Paleozoic (Permian-Carboniferous) formations and it is covered mainly by sandy and sandy-loamy soils (light to middle-textured soils).

The main aquifers are developed in the permeable Triassic and Cenomanian rocks (deep aquifer) and Middle Turonian formations (shallow aquifer). Groundwater in the deep aquifer shows semi-confined to artesian conditions, whereas in the shallow aquifer unconfined conditions occur. Depths of the deep aquifer exceed 200 m.

Figure 1. Location of the Metuje River basin

There is a dense network of groundwater and surface water observation sites in the basin (state monitoring network conducted by Czech Hydrometeorological Institute and additional observation sponsored by Ministry of the Environment), which is mainly attributable to the requirements for monitoring of the important groundwater resources in the basin.

For a number of reasons (mainly for assessing long-term changes in water resources due to climate variability, for assessing the impact of groundwater abstractions on groundwater resources and ecology, and for modelling the interaction between groundwater and streamflow), T.G.M. WRI carries out hydrological monitoring in the upper part of the basin. In this area, the Institute operates three automated water gauging stations, of which two are located on the Metuje mainstream and the third one is sited on the Zdonovsky Brook. Three boreholes that are presently in operation are provided with automated monitoring system and a pressure sensor for water table measurements. Two of them have been drilled into a deep aquifer in Cretaceous formations (the depth of about 180 m) while the remaining borehole monitors a shallow aquifer in the depth of about 3 m. Bucnice experimental meteorological station, which has been in operation since 1963, observes data on the air temperature, air humidity, precipitation and the depth of the snow cover (additional parameters have been observed since 1998). River water stages and flows are observed at a water gauging station, which is located at the most downstream site on the Bucnice Brook.

For the purposes of this study, data observed during the period 1974-2004 were used.

RESULTS

It was calculated by Kněžek and Krátká (2005) that mean volume of the part of the groundwater storage above the altitude of its discharge into the river (circulating component of the groundwater resource) is $24x10^6$ m^3 for the area of the basin upstream from Teplice n. M. water gauging station (89 km^2) and $79x10^6$ m^3 for Hronov station (240 km^2).

Results of analyses of 1976 to 1990 data series show that the largest decrease in groundwater storage in this period was $0.80x10^6$ m^3 (3.3% of the total storage) for Teplice n. M. station and $4.09x10^6$ m^3 (5.2% of the total storage) for Hronov station. These values are relevant to a decrease in base flow by 9.0 mm and 17.04 mm, respectively. In terms of groundwater levels, these values are coupled with a decrease in a selected borehole (VS 3 - Adršpach) by 2.21 m and 2.94 m, respectively.

Several causal factors (mainly long-term increase in the mean air temperature, change in its seasonal distribution and a minor decrease in precipitation) were reflected in the fact that already in 2004 (dry year) the groundwater storage was at a level of 73% of the original values (decrease by 27%) for Teplice n. M. station and of 63% (decrease by 37%) for Hronov station. In 2004, the groundwater level (in the VS 3 borehole) was 2.26 m below that in 2002.

These results are in harmony with those from Bilan and Modflow simulations described for selected climate change scenario (ECHAM4 model, SRES CO_2 emission scenario, 2050 as reference year) in Novický, O. et al. (2006). Changes in the mean water balance components (Bilan simulation) consequently to the climate change are shown in Figure 2.

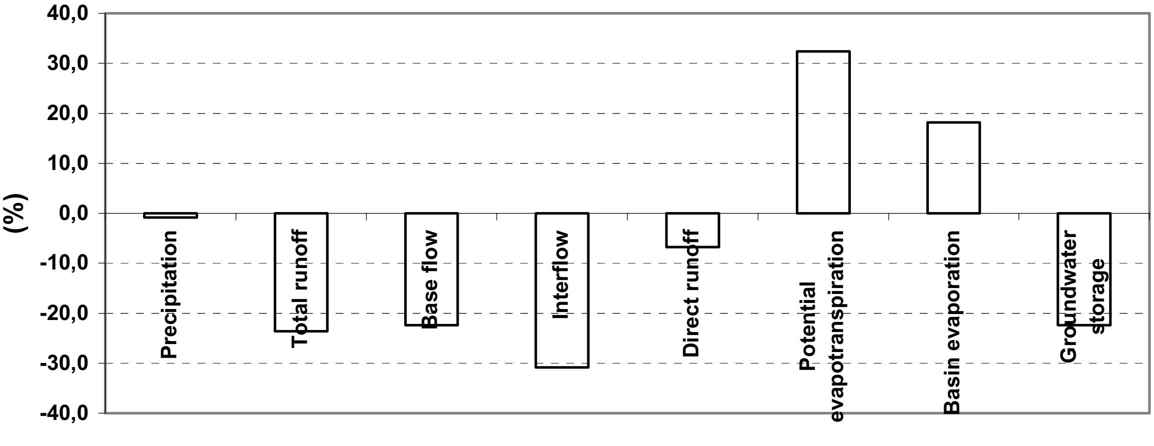

Figure 2. Changes in long-term mean values of water balance components consequently to climate change in the Metuje River basin

Figure 3 illustrates the simulated decrease in the groundwater recharge and a change in its seasonal distribution. The simulated groundwater recharge series affected and not affected by the climate change were used as an input of the Modflow model, which was applied for simulation of the impact of the changed recharge on groundwater levels and on base flow. The simulated maps of the changes in groundwater table show spatial distribution of a decrease in the groundwater level, whose range is around 10 meters and the mean value about 6 meters (Figure 4). The base flow could drop to values that are approximately at levels of the existing groundwater abstractions in the basin (about 100 l s^{-1}). The impact on the groundwater would be also reflected in flow of the Metuje River, which would fully dry in the periods when it is normally almost exclusively fed from the groundwater storage.

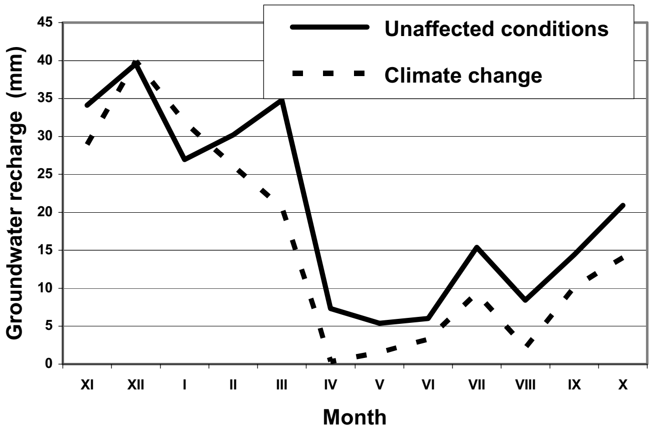

Figure 3. Decrease and change in seasonal distribution of groundwater recharge consequently to climate change in the Metuje River basin

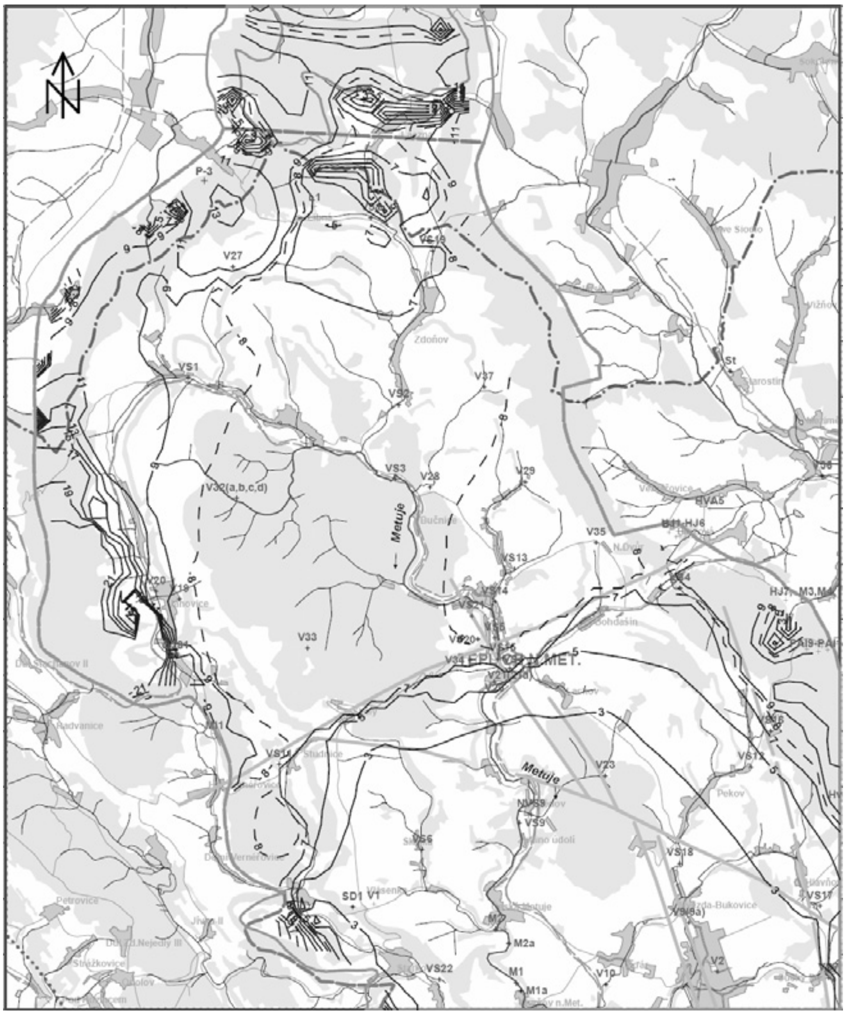

Figure 4. Decrease in groundwater levels (m) consequently to climate change in the Metuje River basin

DISCUSSION AND CONCLUSIONS

It was shown in previous studies (e.g. Kněžek and Krátká, 2005) that groundwater resources in unfavourable hydrogeological conditions, such as those of a crystalline geologic formation with shallow groundwater circulation, are highly sensitive to climate conditions or human influences and that they can rapidly be exhausted.

The results of the studies described in this paper indicate that also groundwater resources in basins with good hydrogeological conditions are highly vulnerable, particularly when they are exposed to a combination of the impacts. In terms of the climate change variables, the impact of the increase in the air temperature can largely be reduced or strengthened by change in precipitation and its seasonal distribution.

The results also indicate that the linked application of the hydrological model (Bilan) and the hydraulic model (Modflow) provides a good tool for this type of the studies. Further improvements, particularly in assessing spatial variability of the impacts, could be achieved by application of regional climate change scenarios. These studies have already been initiated.

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A study on the impact of climate variability through a regional rainfall frequency analysis for Botswana

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Key Words: climate change, regionalisation, l-moments, rainfall quantiles

ABSTRACT

This study based on long term annual rainfall data from 1961-2003 at 11 synoptic stations across Botswana, has concluded that rising rainfall trends for the period up to 1981 have shown decreasing trends with the addition of almost equal number observations in the recent times to the aforesaid data. Regional analysis carried out with the data from the initial period and with the total data, separately showed that all the stations behaved homogeneously and followed a GEV distribution. Rainfall quantiles computed with the total data also showed a decreasing pattern when compared with quantiles estimated using the data series up to 1981. It was also observed that that climate variability in Botswana will have greater impacts on short terms than on longer intervals and that the country could experience 2-17% decrease in rainfall quantiles at a 10-year recurrence interval compared to 0-14% decrease at a 50-year recurrence interval, thus posing a greater threat to food security of the country in the near future.

INTRODUCTION

Information on rainfall magnitude at specified risk or recurrence interval is important for agricultural and water resources planning and management besides others. It is more so for a semi-arid country like Botswana where the annual rainfall is erratic and varies between 250 mm in the south west to 500 mm in the north. The coefficient of variation of the annual average rainfall varies between 03 – 0.5. In the recent past world has been experiencing a substantial increase in green house gas emissions, posing threats such as increase in the global temperature besides changes in other climatic variables such as: rainfall and evaporation (Raskin and Kemp-Benedict, 2004). It is also well known that increase in temperature will accelerate the hydrologic cycle involving changes in precipitation hence in the runoff and in increased frequency of many weather related disasters including floods and droughts. In fact, in the past two decades or so, the world has been witnessing a substantial rise in the number of weather related disasters ending up in huge economic implications. For example, in 2005 the world suffered from huge economic losses to a whooping total of US$ 204 billion nearly doubling the previous record of US$112 billions in 1998.

General Circulation Models (GCMs) the principal tool relating changes in atmospheric chemistry to changes in climatic variables such as temperature and precipitation; though project that a 1.5 to 4.5 ^{o}C rise in global mean temperature would increase the global mean precipitation about 3 to 15%, do not provide the requisite degree of region specific information (Parida et al., 2005) . It is even projected that, some lower latitude basins, may experience reductions in runoff due to a combination of increased evaporation and decreased precipitation (Frederick and Major, 1997). But in areas with increased precipitation, higher evaporation rates may lead to reduced runoff. So, hydrological uncertainties attributed to changing atmospheric chemistry are likely to persist in the foreseeable future. Even a semi-arid country like Botswana has been in the grip of such climatological uncertainties, with de-

creasing rainfall and increasing evaporation rates, which have resulted in affecting nearly 1.5 million people with economic losses over US$ 3 million between 1965 and 2006 (EM-DAT, 2007).
The aforesaid rainfall quantiles in question can be estimated using an appropriate statistical model and an appropriate method of parameter estimation provided that the data do not exhibit any persistence. Yet, small sample sizes, outliers, trend and seasonal behaviour can bring in non-stationarity to the data which may influence the choice of the model and the results. Though seasonal aspects can be overcome by considering annual totals; impact of outliers, small sample size, measurement error and trend in the data would still remain a concern. It has generally been agreed that the method of regionalisation with Probability Weighted Moments or L-Moments method of parameter estimation suggested by Hosking et al (1997), can not only help to overcome the above problems to a great extent, but also be able to identify the underlying statistical model. Even, the use of a regionalisation technique is more apt to this study as the precipitation in an area is generally resultant of a regional phenomenon rather than a local one. However, the local impact, if any, can be captured by combing the result from regionalisation with the local average rainfall while estimating the quantiles by an at-site-regional procedure (Cunnane, 1988). In view of this, an at-site-regional study using annual rainfall data from 11 synoptic stations fairly well distributed across Botswana has been undertaken to make reliable quantile estimates at select recurrence intervals such that impact of the climatic variations, if any, can be studied.

METHODS

To study the impact of climatic variability, it is essential to identify observations related to the non-intervened period such that results obtained using these data could be compared with the results obtained using the total series. Results from a recent study undertaken on the Limpopo basin which covers about one-third of the country, showed a significant change in the rainfall pattern from the year 1982 when basin scale average rainfalls were considered (Parida et al., 2006). Even this conclusion based on intervention analysis was corroborated by the study of Holms and Morgan (1985), who based on Botswana's agricultural statistics between 1980-1985 even showed that the country's cereal production dropped to less than one third between 1982-1985, compared to the productions in 1980 and 1981. Since, much of Botswana's agriculture is rain-fed, it clearly suggested that there has been change in the rainfall regime from 1982. In view of these the observed series up to year 1981 could be considered as the non-intervened part of the total series and the rainfall series observed up to 1981 at each of the synoptic stations would be subjected to regional frequency analyses using the method of L-Moments and the quantiles estimated at different stations using at-site information with regional information. These would then be compared with the quantiles obtained in a similar manner with the entire series to detect changes if any.

Method of L-Moments:

If x_1, x_2, …. , x_N represent ranked annual precipitation values (mm) observed at ay station in the ascending order, then computation of first four Linear moments (L-Moments) λ_1, λ_2 , λ_3 and λ_4 can be carried out (Maidment, 1993), using the Eqns (1)-(4) below.
$\lambda_1 = E[x]$ (1)
$\lambda_2 = (1/2)\, E[x_{(1:2)} - x_{(2:2)}]$ (2)
$\lambda_3 = (1/3)\, E[x_{(1:3)} - 2x_{(2:3)} + x_{(3:3)}]$ (3)
$\lambda_4 = (1/4)\, E[x_{(1:4)} - 3x_{(2:4)} - 3x_{(3:4)} - x_{(4:4)}]$ (4)
where, λ_1, λ_2 , λ_3 and λ_4 respectively represent the parameters related to location, scale, shape and peakedness. The connotations (1:2) and (2:2) in the Eqn. (2), means the first and second large value respectively in a sample of size of two drawn from the series in question. In a similar manner appropriate connotations can be used in other equations.

Then the dimensionless L-moments can be computed from Eqns. (5)-(7) below:

L-Coeff. of Variation (L-Cv), $\tau_2 = \lambda_2/\lambda_1$ (5)

L-Coeff. of Skewness (L-Sk), $\tau_3 = \lambda_3/\lambda_2$ (6)

L-Coeff. of Kurtosis (L-Ku), $\tau_4 = \lambda_4/\lambda_2$ (7)

Using the L-Moment procedure (Hosking et al., 1997), discordant sites whose at-site (D (I)) values are markedly different from other sites if any, are identified and removed from analyses if D(I) was greater than 3.0. Then through a simulation exercise the rain stations are tested for their homogeneity (H). This can be established either through the use of either L-Cv or (L-Cv/L-Kutosis) or (L-Skew/L-Kurtosis) values to represent V in Eqn.(8) below. For example, if Cv is considered on its own then H can be computed from:

$H = (V - \mu_V) / \sigma_V$ (8)

where, V = weighted (standard deviation) of τ_2 values

μ_V, σ_V =the mean and standard deviation of N_{sim} values (=500) of V

Depending on the values of H, i.e. either less than 1, or between 1 and 2, or greater than 2, a region containing a group of stations, can be connoted as, 'acceptably homogeneous', 'possibly homogeneous', or 'definitely heterogeneous'. Finally, the goodness-of fit measure is computed from:

$$Z^{Dist} = \frac{\tau_4^{Dist} - \bar{t}_4 + \beta_4}{\sigma_4} \qquad (9)$$

where, $\bar{t}_4$ = average L-Kurt value computed from the data of the region

β_4 = bias in L-Kurt values ,t_4, computed from the original data.

τ_4^{Dist} = average of L-Kurt value computed from simulation of a fitted distribution.

σ_4 = standard deviation of L-Kurt values obtained from simulated data

All distributions whose absolute Z value is less than or close to 1.64 qualify as a possible candidate. Alternatively, if the average of L-Skew and L-Kurtosis values for a group of homogeneous rain stations, is plotted on a L-Skew and L-Kurtosis diagram containing theoretical curves from different distributions, its vertical distance to the nearest curve suggests the possible candidate.

Using the regional parameters for the identified distribution, standardised quantiles for the region at specified recurrence intervals (T) (or probabilities of non-exceedence) can be computed which are then multiplied by the station specific annual average rainfall to obtain the desired rainfall quantiles for the station in question. For example if the regional distribution was identified as Generalised Extreme Value, the standardised quantile (SQ = $x_T/\bar{x}$) can be computed from :

$SQ = \xi + \alpha [1 - \{- \log F (x)\}^k] / k$, for $k \neq 0$ (10).

where F(x) = Probability of non-exceedence corresponding to recurrence interval T ; ξ = the location parameter, α = scale parameter and k = the shape parameter and $\bar{x}$ = Annual average rainfall .

Then the desired rainfall quantile for a recurrence interval of T, $x_T = SQ. \bar{x}$

STUDY AREA, ANALYSIS AND DISCUSSION OF RESULTS:

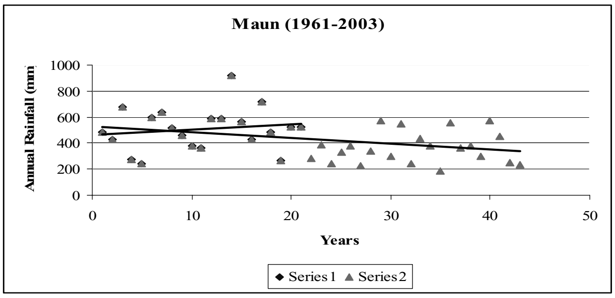
Eleven synoptic stations spread across Botswana (barring the Kalagadi desert region) with long records, were chosen for this study. Details of their location and the period of observation have been furnished in Table 1. As discussed earlier, data at each of these stations were analysed in two steps, one which considered observations up to the year 1981 (say the non-intervened series) and the other which considered the entire period of observations (total series). Rainfall statistics for both the series have been computed and tabulated in Table 1. It shows that average rainfall at each of these stations have decreased over the years suggesting that Botswana in general is in the grip of the climate change. Even, the CVs (co-efficients of variation) over the years have mostly increased or at the most remained unchanged, suggesting a very erratic rainfall when compared with the non-intervened series.

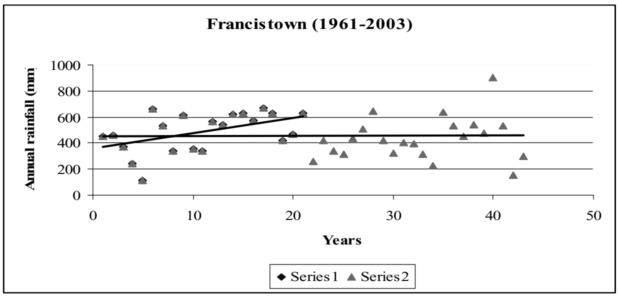
Table 1 Details of location of rain gauge stations and rainfall statistics at such stations in Botswana

Name of rain gauge station	Location		Period of Data	Rainfall statistics up to the year 1981			Rainfall statistics for the entire period		
	Latitude	Longitude		Average (mm)	Std. Dev. (mm)	CV	Average (mm)	Std. Dev .(mm)	CV
Mahalapye	23° 7’ S	26° 50’ E	1961- 2003	453.0	149.9	0.33	434.5	151.8	0.35
Francistown	21° 10’ S	27° 31’ E	1961- 2003	486.1	151.9	0.31	458.9	158.3	0.34
Gantsi	21° 41’ S	21° 38’ E	1961- 2003	441.1	178.4	0.40	417.7	159.3	0.38
Goodhope	25° 28’ S	25° 26’ E	1968-2003*	532.0	106.4	0.20	484.6	133.3	0.28
Kasane	17° 49’ S	25° 9’ E	1961-2003#	653.1	156.7	0.24	588.3	165.0	0.28
Letlhakeng	24° 4’ S	25° 2’ E	1962-2001	432.7	124.6	0.29	382.8	130.2	0.34
Maun	18° 59’ S	23° 25’ E	1961- 2003	507.7	162.3	0.32	433.2	158.5	0.37
Pandamatenga	18° 36’ S	25° 38’ E	1962-2001!	584.8	179.7	0.31	543.9	162.8	0.30
Shakakwe	18° 23’ S	21° 25’ E	1961- 2003	545.1	171.6	0.31	496.9	166.9	0.34
SelebiPhikwe	21° 58’ S	27° 50’ E	1973-1998!	494.4	92.2	0.19	406.8	120.1	0.30
Tsabong	26° 0’ S	22° 24’ E	1961- 2003	318.5	140.7	0.44	296.1	128.4	0.43

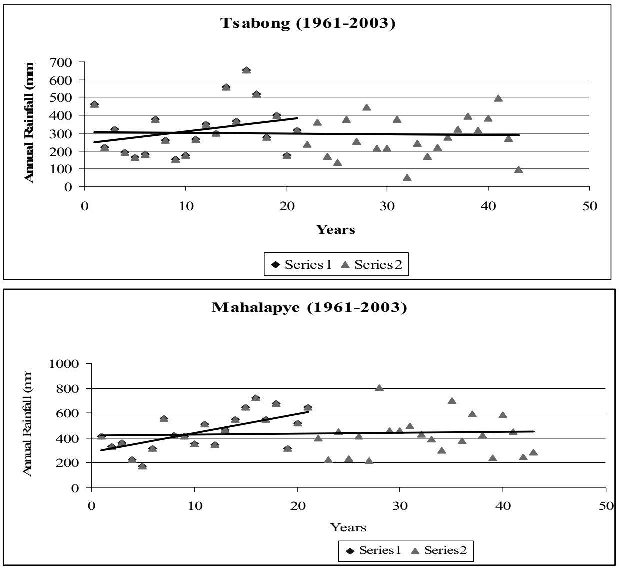
Missing data for the years: *1975., # 1967; ! 1993 and ^ 1992

In addition to these, trends for the non-intervened or the initial series and the total series at each of the rain gauge stations were studied. It was found that the rainfall in the initial period had a rising trend which was found to be decreasing considerably when data for the entire period were considered as can be seen from some of typical plots given in Fig. 1.





(a) (b)



(c) (d)

Figure 1 Typical plots of observed rainfall trends in the initial period (up to 1981) (series 1) and total period (series 2) at (a) Maun; (b) Francistown; (c) Tsabong and (d) Mahalapye raingauges.

The two series were then subjected to the regional analyses using the method of L-Moments, separately and the L-Cv, L-Skew, L-Kurt and the Discordance values [D (I)] computed in each case have been tabulated in Table 3. It was observed that in both the situations, none of the stations showed any sign of discordancy, suggesting that the stations were homogeneous.

Table 3 L-Moments statistics along with Discordance values at the rain gauge stations with non-intervened series/data for the initial period (up to 1981) and the total series.

Name of rain gauge	Using Data for the Initial Period					Using Data for the Total Period				
	Yr	L-Cv	L-Skew	L-Kurt	D(I)	Yr	L-Cv	L-Skew	L-Kurt	D(I)
Mahalapye	21	0.1980	0.0650	0.1177	0.18	43	0.2023	0.1027	0.1314	0.04
Francistown	21	0.1829	-0.1315	0.0983	1.69	43	0.1980	0.0185	0.1244	0.81
Gantsi	21	0.2353	0.1538	0.1339	0.79	43	0.2129	0.1644	0.1823	1.90
Goodhope	13	0.1332	0.0693	0.1811	1.08	35	0.1636	0.0212	0.1162	0.83
Kasane	20	0.1480	-0.0197	0.1493	0.52	42	0.1648	0.1157	0.1042	1.19
Letlhakeng	20	0.1609	-0.0824	0.2831	2.25	40	0.1951	0.0016	0.1273	1.32
Maun	21	0.1863	0.0752	0.2109	0.24	43	0.2086	0.1162	0.1003	1.06
Pandamatenga	21	0.1821	0.0481	0.0751	0.87	40	0.1741	0.0696	0.0822	0.94
Shakakwe	21	0.1863	0.0681	0.1523	0.02	43	0.1831	0.1015	0.1545	0.87
SelebiPhikwe	9	0.1209	0.1283	0.2969	1.79	25	0.1769	0.0693	0.1097	0.19
Tsabong	21	0.2522	0.2188	0.1368	1.58	43	0.2455	0.1311	0.1419	1.81

Using simulations with 500 samples containing similar lengths of record as that has been observed, heterogeneity measures were computed for the non-intervened series and the total series separately under three categories viz: for L-Cv, L-Cv / L-Skew and L-Skew/ L-Kurtosis and have been tabulated in Table 4. It is evident from the results that, not only the stations were 'acceptably homogeneous' for both series, but also suggested the safe transferability of regional information to other desired sites in the study area.

Table 4 Heterogeneity Measures derived through simulation for the two data series

Standardized Test Values	Using Data for the Initial Period	Using Data for the Total Period
L-Cv	0.85	0.69
L-Cv / L-Skew	-0.54	-0.82
L-Skew/ L-Kurt	-1.77	-1.74

Z-statistics computed using Eqn.(9) with the total series, it was found that three distributions, namely the Generalised Extreme Value (GEV), Generalised Normal (GN), and Pearson Type III (PT III) were found to be the possible candidates which can describe the observed data well. Even these three distributions were flagged of as the plausible distributions when the series for the initial period were considered. However, for computation of standardised rainfall quantiles at select recurrence intervals viz: 10, 20 and 50 years, GEV distribution has been chosen as the underlying distribution. Then rainfall quantiles at each of the rain gauge stations were computed at the selected recurrence intervals and tabulated in Table 5.

A close observation of Table 5 shows that the quantiles using the total series decreased in general when compared to the quantiles estimated from the initial series. It was however interesting to note that the average percentile reduction in the rainfall quantiles marginally deceased with the increase in the recurrence interval. Even the range of change across the stations seemed to reduce for higher recurrence intervals. For example while the change at a recurrence interval of 10 years were to found to vary between (-2.6%) and (-16.4%); such changes at recurrence interval of 50 years were found to vary between (-0.8%) and (-13.8%).

CONCLUSIONS

Based on the results from the 11 synoptic rain gauge stations studied across Botswana, it can be concluded that, Botswana is experiencing the global phenomenon of climate change with decreasing trends and increasing co-efficient of variation in rainfalls, posing a greater threat to the food security of the nation.

The study also discussed the various homogeneity indices obtained from the analyses to evaluate if the stations were homogeneous and if the regionalization results were transferable to each site within the region?. It was found from the analyses that the entire country behaved like a homogeneous region and the data followed a Generalized Extreme Value (GEV) distribution besides two others, suggesting that the regional GEV parameters could be transferred to the specific sites with confidence.

Table 5 Rainfall quantiles computed at the synoptic rain gauge stations for the initial and the total period.

Name of rain gauge Station	Rainfall Quantiles (mm) for the Initial Period			Rainfall Quantiles (mm) for the Total Period		
	T= 10 yr	T= 20 yr	T= 50 yr	T= 10 yr	T= 20 yr	T= 50 yr
Mahalapye	652	713	781	636 (-2.6)	705 (-1.1)	784 (+0.4)
Francistown	700	765	838	672 (-4.0)	744 (-2.7)	828 (-1.2)
Gantsi	635	695	760	611 (-3.8)	677 (-2.6)	754 (-0.8)
Goodhope	766	838	917	709 (-7.4)	786 (-6.2)	874 (-4.7)
Kasane	940	1029	1126	861 (-8.4)	954 (-7.3)	1062 (-5.7)
Letlhakeng	623	681	746	560 (-10.1)	621 (-8.8)	691 (-7.4)
Maun	731	799	875	634 (-13.3)	702 (-12.1)	782 (-10.6)
Pandamatenga	841	920	1007	797 (-5.2)	883 (-4.0)	983 (-2.4)
Shakakwe	785	858	940	739 (-5.9)	819 (-4.5)	911 (-3.1)
SelebiPhikwe	712	779	852	595 (-16.4)	660 (-15.3)	734 (-13.8)
Tsabong	458	501	549	433 (-5.5)	480 (-4.2)	534 (-2.7)

Average change (%)	(-7.5)	(-6.25)	(-4.72)
Maximum Change (%)	(-16.4)	(-15.3)	(-13.8)*
Minimum Change (%)	(-2.6)	(-1.1)	(-0.8)

Figures in the brackets ( ) indicate Percentage changes; * without the positive value

Using the regional parameters with at-site rainfall averages, quantiles were estimated at 10, 20 and 50 years recurrence intervals, separately considering the series of observations up to 1981 and the entire series up to 2003, which included almost equal number of additional data under the recent conditions. Based on the results, it can generally be said that climate variability in Botswana will have greater impacts on short terms than on longer intervals in that the country could experience 2-17% decrease in rainfall quantiles at a 10-year recurrence interval compared to 0-14% decrease at a 50-year recurrence interval.

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Uncertainties in estimation of design peak flow with 100-year return period

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ABSTRACT

One of the basic tasks of engineering hydrology is the determination of the hydrological design quantities. In analysing and detailed studying of the flood waves, the highest attention is paid to the peak flows and to the peak flood levels. The 100-year peak flow $Q_{max.100}$ belongs to the basic characteristics in each catchment. For estimation of the N-year peak flows in small catchments, several methods are available. Uncertainties associated with such an estimate are largely depending on the method used, as well as on the period of the observed peak flow data. The aim of this contribution is the illustration of these uncertainties and a comparison of specific peak flow values with the exceedance probability once in 100 years (100-year, q_{100}) in small catchments using data from four experimental microcatchments of Institute of Hydrology, Slovak Academy of Sciences in the Field Hydrological Laboratory. Following microcatchment water level recorder data of yearly peak flows were evaluated: Rybarik (agricultural microcatchment, 0.119 km^2), Lesny (hornbeam forest, 0.0864 km^2), Cingelova (spruce forest, 0.22 km^2), and the whole Mostenik catchment (25 % of the mixed forest, 17.2 km^2). The used database covers a 41-year period 1965–2005. For determination of the $q_{max.100}$, methods of the mathematical statistics (according to the DVWK (1999) methodology), and three indirect estimates were applied (1. Hradek; 2. ERCN and 3. OTN ZP). The $q_{max,100}$ estimates by different methods differ within quite a range. From the practical point of view, we should as suitable consider those results obtained by the statistical estimates. This conclusion is based upon the need to design water structures to the same desired safety by different methods, especially on the boundary between small and very small catchments. In an ideal case, results obtained by statistical methods, regional formulae, regional frequency analysis, and various empirical formulae, should be equal.

INTRODUCTION

For estimation of the N-year peak flows, several methods are available (Kohnová and Szolgay 1995, 1996; Szolgay et al 2003, 2005): i) methods of mathematical statistics; ii) empirical relationships (volume or intensity based); iii) rainfall-runoff models, or iv) regional estimates methods. Uncertainties associated with such estimates are largely depending on the method used as well as on the period of the observed peak flow data.

The aim of this contribution is the illustration of these uncertainties and a comparison of specific peak flow values with the exceedance probability once in 100 years (100-year, q_{100}) in small catchments using data from four experimental catchments of Institute of Hydrology, Slovak Academy of Sciences (IH SAS) in Mostenik brook catchment.

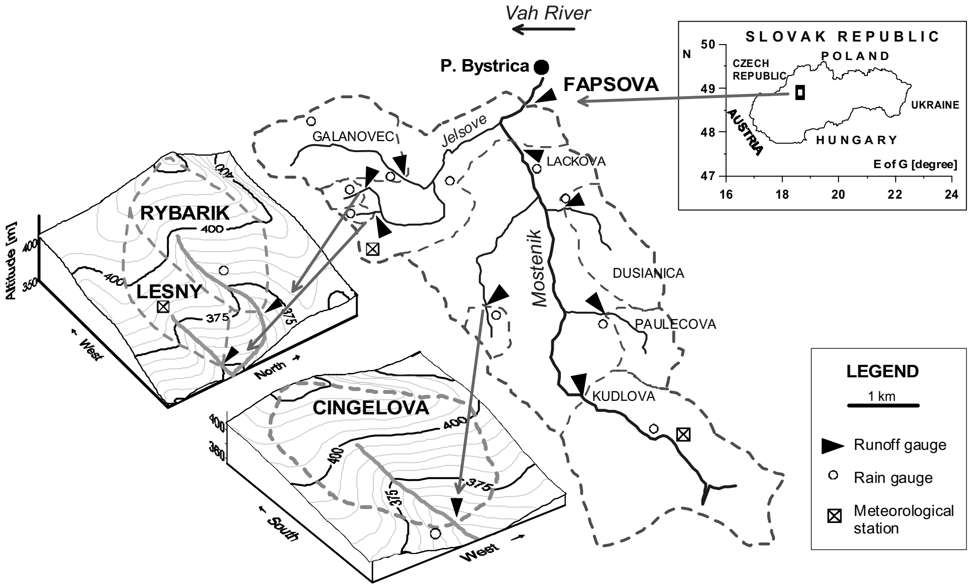


Figure 1. Location of the Mostenik brook catchment, and three microcatchment.

Description of the experimental catchments and material

Due to evaluation of water balance in small basins, some experimental microbasins were established in Slovakia in the fifties of the last century. The experimental basin of the Mošteník brook (FHL) was one of the first experimental catchments in the former Czechoslovakia established by Institute of Hydrology of Slovak Academy of Sciences (IH SAS) in 1958. It is situated near Považská Bystrica (18°40' East longitude, 49° North latitude) in the Puchov highland. The Mošteník brook basin is a small left hand part of the Vah River catchment, which is the main tributary of the Danube River from the territory of Slovakia (Fig. 1). It is considered as representative basin for the central hilly region of Slovakia. Experimental catchment of the Mostenik brook up to its outlet point Fapsova has its area of 17.2 km^2. Water level observations in the Mostenik catchment started gradually in 1962. The whole catchment has been divided into eight partial subcatchments with the catchment area from 0.0864 up to 12.61 km^2 (Fig. 1). For evaluation of the surface runoff, measuring weirs of the Thomson type were installed (large – 90^o and small – 45^o) in 1958–1962, at the outlet points of the Rybarik, Lesny, and Cingelova catchments. The water levels were recorded continuously by a daily float type recorder.

Table 1. Basic catchment characteristics and basic runoff characteristics in experimental microcatchments IH SAS Rybarik, Lesny and Cingelova for the period 1964/65–1993/94

Catchment		Rybarik	Lesny	Cingelova
Area	[km^2]	0.119	0.086	0.22
Forestation	[%]	10	90	95.5
Min/Mean/Max catchment altitude	[m a.s.l.]	369/401/434	350/380/415	355/382/435
Long-term mean yearly precipitations.	[mm]	743.9	732.5	739.4
Long-term yearly runoff	[mm]	237.2	163.4	194.9
Runoff coeff.		0.318	0.223	0.263

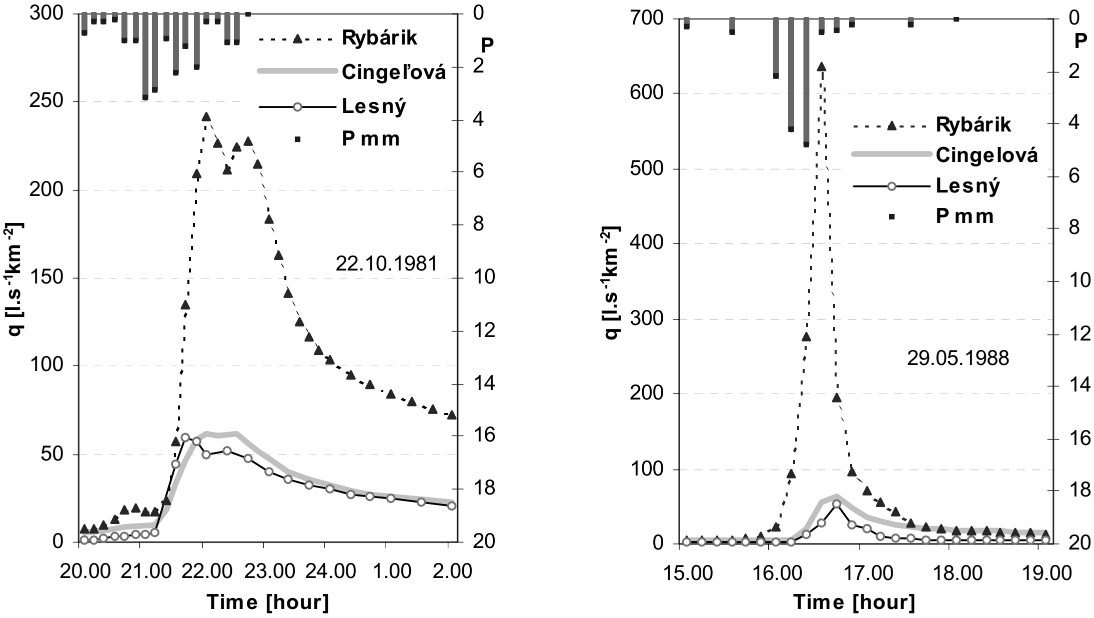


Figure 2. Comparison of the hourly specific flows q [l.s^{-1}.km^{-2}] in the three experimental microcatchments Rybarik, Lesny, and Cingelova, during rainfall-runoff events on 22 October, 1981 and 29 May, 1988.

Annual maximum specific flows

In Fig. 2, a time course of the hourly specific flows q [l.s^{-1}.km^{-2}] is shown as an example in three experimental microcatchments Rybarik, Lesny, and Cingelova, from two approx. equal rainfall–runoff events in all three catchments, on 22 October 1981 and 29 May 1988. During the 40 years of observations (1964/65–2003/04), the highest mean daily specific flow (300 l.s^{-1}.km^{-2}) was observed on 20 August 1966 in the Rybarik microcatchment. In Table 1, the basic runoff characteristics from the 1964/65–1993/94 period are demonstrated (according to Pekárová et al., 2005).

The observed values of the mean annual maximum specific flows *q* are presented in Fig. 3, from the microcatchments Rybarik, Lesny, Cingelova, and small catchment Mostenik: Fapsova, for the 1965–2004 period. The highest water level during the history of observations on the brook Jelšové at the Rybarik station has been recorded on 25 July 1970 (59.5 cm, discharge 365 l.s^{-1}). The rainfall depth on this day at Rybarik station was 39.1 mm.

Statistical estimates of the N-year maximum specific flows

For the estimation of design discharges in the experimental catchments, we applied the DVWK (1999) methodology. It is based on the possibility to use a wide variety of the theoretical probability distribution curves, and three methods for estimation of their parameters, with a simultaneous application of a statistical test for decision as to their selection.

For estimation of probability distribution function parameters, three methods were used:

(i) The method of moments (MM),
(ii) The method of the maximum likelihood (MLM),
(iii) The method of the probability weighed moments (WGM).

By application of this methodology, following probability distributions were applied: Gumbel distribution (EV1), generalized extreme value distribution (AE), Rossi distribution (ME), 3-parametric lognormal distribution (LN3), 3-parametric Pearson distribution (P3), 3-parametric logPearson distribution (LP3), and 3-parametric Weibull distribution (WB3).

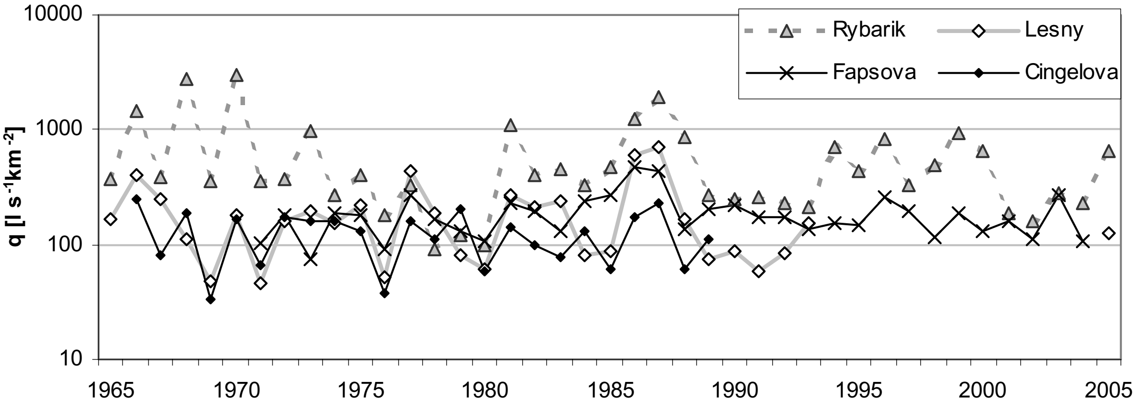


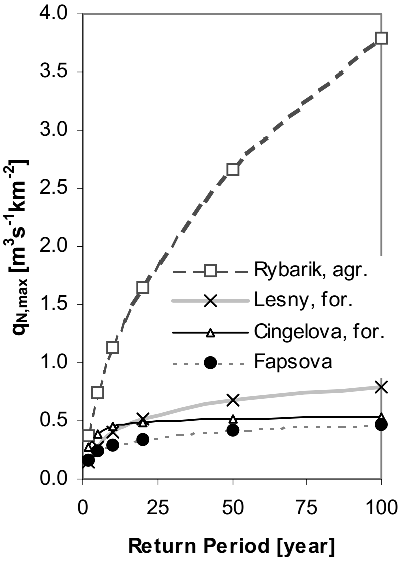
Figure 3. Time series of the annual maximum specific flows in [l.s^{-1}km^{-2}], for the observation period.

Estimates of the design maximum specific flows IN SMALL CATCHMENTS by different methods

The estimation results of the N-year maximum specific flows from the three microcatchments and from small catchment Fapsova with various types of the vegetation cover are shown in Fig. 4. Maximum value of the 100-year maximum specific flow extrapolated from the theoretical distributions from the agricultural microcatchment Rybarik was estimated to 3.8 m^{3}s^{-1}km^{-2} (Table 2). The 100-year maximum specific flow value from the forested catchment Lesny was 0.828 m^{3}s^{-1}km^{-2}. The extrapolation of the $q_{max,100}$ values represents only an estimate by statistical methods, although based on the 30 to 41 years of the data series. However, these values are based upon the concrete observed historical data and have real base therefore will be used as a basis for comparison here.

Table 2. 100-year maximum specific flows $q_{max.100}$ in [m^{3}s^{-1}km^{-2}] of the agricultural microcatchment Rybarik, of the forested microcatchments Lesny and Cingelova, and of the small catchment Fapsova, determined by various methods of the indirect estimate

Catchment	Area km^2	Statistical estimate DVWK (1999)	Hydrological regulation Hradek (1999)	ERCN Dumbrovsky, et al. (2001)	OTN-ZP 3112-1:03 (2003)
Rybarik	0.119	3.815	1.882	1.765	6.719
Lesny	0.0864	0.828	0.898	0.347	6.817
Cingelova	0.22	0.600	0.868	0.227	6.441
Fapsova	17.2	0.510	1.258	0.329	1.713



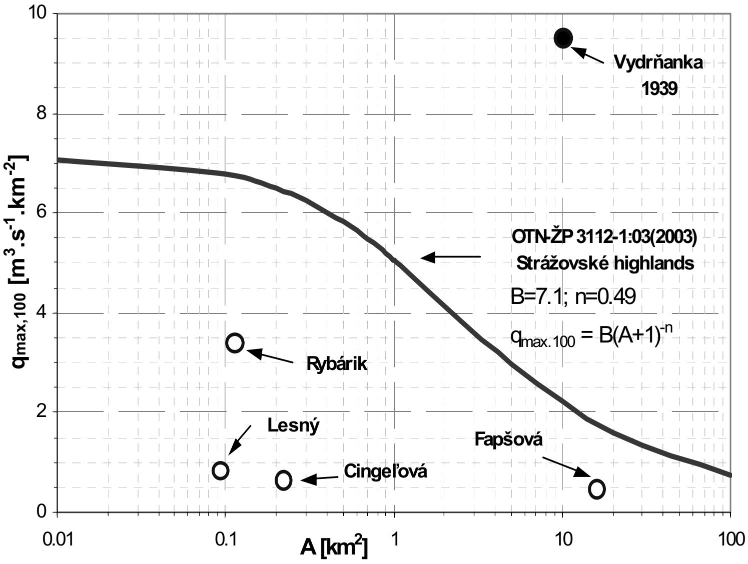


Figure 4. N-year maximum specific flow values in the three micro-catchments and small catchment Fapsova (Rybarik – agricultural, Lesny and Cingelova – forested).

Figure 5. 100-year peak specific flow in relation to catchment area A (bold line) according OTN ŽP (2003). Statistical estimate of 100-year peak specific flow in four experimental basins of FHL (circles) and estimated specific flow of Vydrňanka in 1939 (full dot)

Empirical indirect methods of estimating of the 100-year peak specific flows

The estimation of design peak flow with a 100-year return period for the analysed catchments by empirical approaches shows different results. For the design peak flow estimates on very small catchments in Slovak conditions, methods based on the rainfall intensity relations proved useful as those according to the formulae of Hrádek (1989), and Dumbrovský et al. (2001). For comparison, the empirical regional relationship according to the technical standard of the Slovak Ministry of Environment OTN-ZP 3112-1:03 (2003) were also applied. The results are summarized in Table 2.

DISCUSSION AND CONCLUSIONS

The highest estimates, which we assume as not real, were obtained by regional formulae. We do not recommend using it for very small catchments. For catchments under 1 km^2, results relatively close to statistical methods are those obtained by the Hrádek (1989) method. The ERCN method according to Dumbrovský (2001), in all subcatchments underestimates the 100-year peaks, and is sensitive to the CN number determination.

The agricultural Rybarik catchment 100-year specific peak $q_{max.100}$, estimated by technical standard of the Ministry for the Environment of the Slovak Republic (OTN ZP) as 6.7 m^{3}s^{-1}km^{-2}, is not unrealistic. Peak specific flows of about 10 m^{3}s^{-1}km^{-2} are not rare in the flysh regions of Slovakia. In Dub (1940), there is a detailed description of flash flood on Vydrnanka (Biela Voda tributary from the flysh Javorníky mountains, catchment of the middle Vah River) on 17 June 1939, at which "…. the rain was so dense, that you could not see to ten steps and the valley slopes were all covered by water which rushed to the brook …". The author determined the specific peak of this flood to appr. 9.0 m^{3}s^{-1}km^{-2} (Fig. 5). Similarly, during the flood of 20 July 1998 on Mala Svinka brook (the flysh part of the Torysa catchment), the specific peak exceeded at locations Rencisov and Jarovnice the 10 m^{3}s^{-1}km^{-2} value (Svoboda, Pekárová, 1998), with forestation of these catchments reaching 80 %.

In case of the forested microcatchments Lesny and Cingelova, the regional method highly overestimates (by an order of magnitude) the $q_{max.100}$ value, as compared with that determined by statistical methods. Should this simple formula be used for catchments under 20 km^2, the need would emerge to incorporate in it at least a correction factor to account for the catchment forestation.

As it can be seen (and was expected), the $q_{max,100}$ estimates by different methods differ within quite a range. From the practical point of view, we should as suitable consider those results obtained by the statistical estimates. This conclusion is based upon the need to design water structures to the same desired safety by different methods, especially on the boundary between small and very small catchments. In an ideal case, results obtained by statistical methods, regional formulae, regional frequency analysis, and various empirical formulae, should be equal.

The wide use of such formulae is expected in the preparation of the flood risk maps in small catchments of the Slovak Republic. In order to arrive at spatially consistent flood risk estimates it will be necessary to select, and/or to develop a design flood estimation procedure, which can be proved to deliver values comparable to those of statistical estimates in a sufficiently large group of control catchments with a representative spatial distribution over the territory of Slovakia.

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Water management innovation for meeting Climate change effects and European Water Framework Directive targets: Pilot study Lankheet

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Keywords: flooding, groundwater, stream flow, surface water, water storage, water framework directive**.**

ABSTRACT

The very wet conditions of recent years in Europe have made it clear that measures will have to be taken in this century to prevent flooding. The question is how to manage groundwater in order to reduce the anticipated increased hydrological risk. Furthermore the surface water quality in the Netherlands is insufficient to meet the standards of the Water Framework Directive. The required improvements are difficult to obtain because the diffuse loads of nutrients from agricultural use can not be reduced so easily. This demands for innovative solutions with respect to improve the surface water quality by means of purification in reed fields and use it as well to reduce the effects of the anticipated climate change. An experimental evidence on a practical scale is lacking and therefore in the woodland area of Lankheet in the eastern part of the Netherlands, 3 ha has been planted with reeds to purify the river water. The aim of the study is further to store the purified water in the groundwater in order to reduce climate change effects. For the hydrological situation a scenario study was set up, using a regional hydrological model to simulate the groundwater flow together with the water flow in a network of water courses. Possible measures have been analysed to reduce peak flows and to increase the lower flows in summer. The analysis will give knowledge on the multifunctional use of such a system.

INTRODUCTION

The Netherlands was originally a marshy delta formed by the rivers Rhine and Meuse. A rise in sea level, coupled with subsidence of the ground level following the drainage of peat bogs and their conversion to farmland means that more than half the country is now below sea level (the low-lying part); the remainder is only slightly above sea level. Throughout the country the water table is shallow (between 0.3 and 2.5 m below the soil surface) and a dense network of engineered watercourses is needed to drain the land. The very wet conditions of recent years in Europe have made it clear that measures will have to be taken in this century to prevent flooding. As indicated in the recent published IPCC report (IPCC 2007), the anticipated climate change will have a crucial effect on groundwater and surface water. The question is how to manage groundwater in order to reduce the anticipated increased hydrological risk.

The objectives of the European Water Framework Directive (WFD) focus on sustainable water use by protection and improvement of the surface and groundwater, using the river basin as the focal point. In a tentative study, the consequences of the WFD for agriculture in the Netherlands was carried out for nutrients and pesticides in fresh water ecosystems (Bolt & Leenders 2004). The results indicated that the surface water quality in the Netherlands is insufficient to meet the standards of the Water Framework Directive. The possible consequences of the Directive are considerable, in larger parts of the Netherlands arable land should be taken out of production, because the diffuse loads of nutrients from agricultural use cannot be reduced so easily (Bakel 2006). This situation demands for innovative solutions with respect to reduce the anticipated effects of climate change, and to improve the surface water quality on meeting the WFD targets.

In this paper we report on a project which is presently carried out in the Eastern part of the Netherlands. It's an experimental set-up in order to improve the water quality of the surface water and to reduce the effects of the anticipated climate change.

METHOD

The effects of climate change and meeting the target for the WFD demands for innovative solutions. In an experimental set-up the purification of the water in reed fields is monitored and investigated, together with the reduction of peak flows. A schematic layout of the set-up, the so-called model Vereijken, is shown in Figure 1. An experimental evidence on a practical scale is lacking and therefore in the woodland area of Lankheet in the eastern part of the Netherlands, an area of 3 ha has been planted with reeds to purify the river water. Reed is able to take up nutrients and phosphorus, it is known that uptake of P is in the order of 50 kg per ha per year. The purified water can be stored in designated areas. Further benefit is to replenish the groundwater in order to recover the terrestic ecosystem from too dry conditions. Also the water can be retained in the reed fields and in the forest to prevent flooding downstream. A promising measure is also to periodically harvest the reeds to be used as bio fuel.

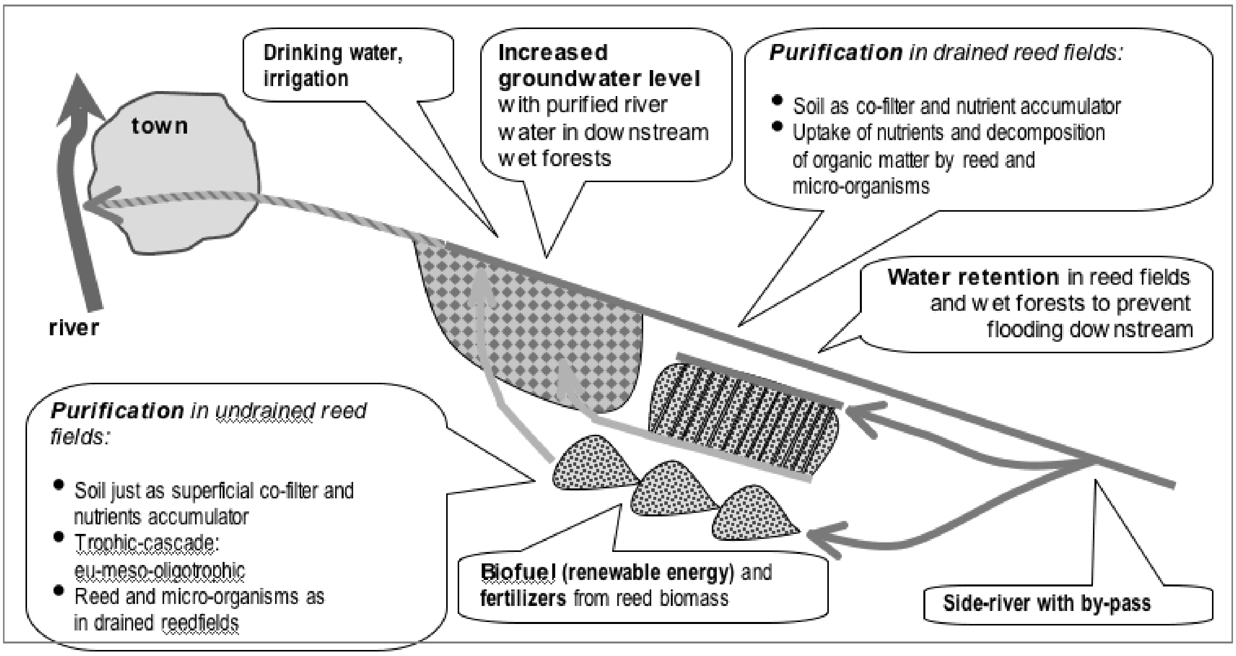

Figure 1. Schematic layout of the experimental site (Vereijken and van der Werf, 2007)

Climatologists anticipate that the climate in the near future, say around 2050, will be warmer and wetter. The Dutch Royal Meteorological Institute predicted a set of climate change scenarios, based on moderate warmer or warmer conditions, using the data and methods given in the 4th IPCC report. The average temperature will rise for the two scenarios one or two degrees respectively. Furthermore it is expected that the air circulation could change. For a temperature rise of two degrees, including the change in air circulation, the so-called W+ scenario, the average annual rainfall will decrease in summer by 19% and increase in winter by 14% (Hurk et al. 2006). The annual potential evapotranspiration will increase by 15%. It is further expected that the rainfall in a period of 10 days will increase by 12% in winter and 10% in summer. Based on these predicted changes historical meteorological data on a daily base was transformed into a new series applicable for the period around 2050. Fife years of meteorological data on a daily basis were selected for the simulations with the hydrological model, being the period 1994-1999. The year 1998 was extreme wet, resulting in an average annual rainfall for this period of 863 mm, for the climate change scenario this increases to 897 mm per year (increase of 4%). The average potential evapotranspiration for grass was 539 mm per year and for the climate change scenario it increases to 620 mm. In the 5 years high intensity rainfall events of 30-40 mm/d occurred 6 times and events of 40-50 mm/d occurred 2 times.

THE COMBINED SURFACE AND GROUNDWATER FLOW MODEL SIMGRO

SIMGRO (SIMulation of GROundwater and surface water levels) is a distributed physically-based model that simulates regional transient saturated groundwater flow, unsaturated flow, actual evapotranspiration, sprinkler irrigation, stream flow, groundwater and surface water levels as a response to rainfall, reference evapotranspiration, and groundwater abstraction. To model regional groundwater flow, as in SIMGRO, the system has to be schematised geographically, both horizontally and vertically. The horizontal schematisation allows input of different land uses and soils per subregion, in order to model spatial differences in evapotranspiration and moisture content in the unsaturated zone. For the saturated zone various subsurface layers are considered (Fig. 2). For a comprehensive description of SIMGRO, including all the model parameters readers are referred to Querner (1997) or Walsum et al. (2004).

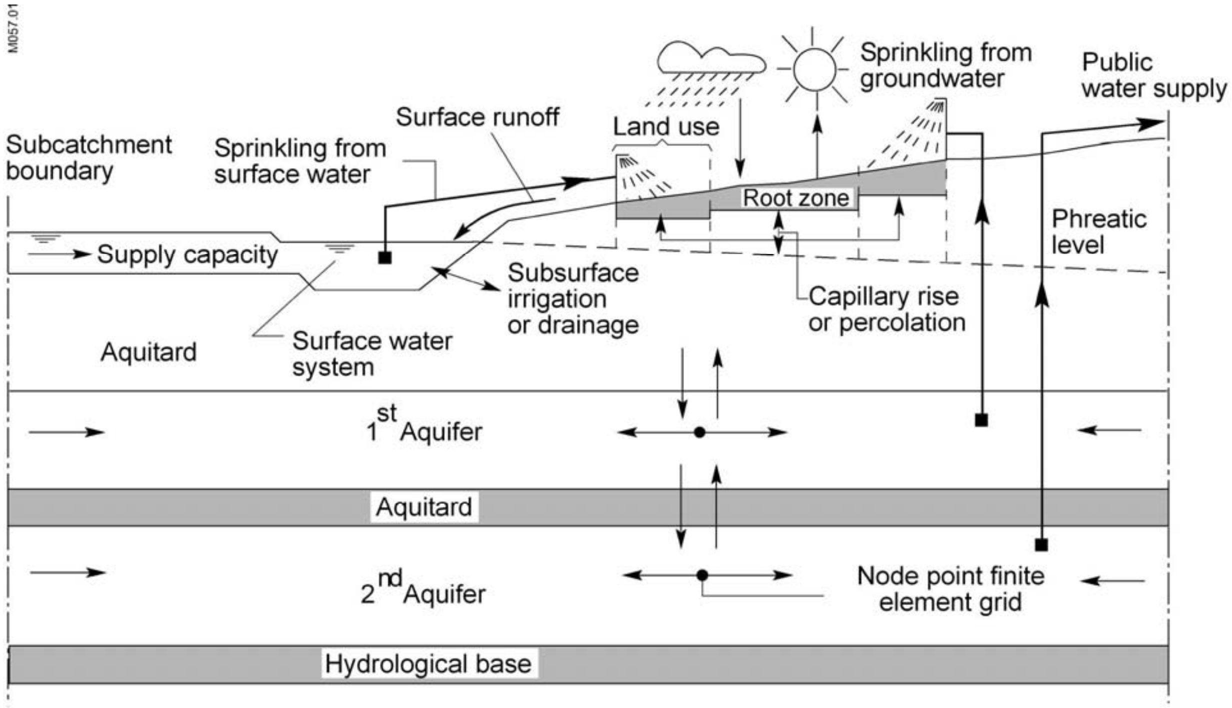

Figure 2. Schematization of water management in the SIMGRO model. The main feature is the integration of the saturated zone, unsaturated zone and surface water systems (Querner, 1997).

In SIMGRO the finite element procedure is applied to approach the flow equation which describes transient groundwater flow in the saturated zone. The unsaturated zone is represented by means of two reservoirs, one for the root zone and one for the underlying soil (Fig. 2). The calculation procedure is based on a pseudo-steady state approach, using generally time steps of up to one day. Evapotranspiration is a function of the crop and moisture content in the root zone.
In the model, four different categories of ditches (related to its size) are used to simulate the drainage. This interaction between surface water and groundwater is calculated for each category using a

drainage resistance and the difference in level between groundwater and surface water (Ernst 1978). The surface water system is modelled as a network of reservoirs. The outflow from one reservoir is the flow entering the next reservoir, and surface water levels depend on the amount of storage and discharge from a reservoir.

STUDY AREA AND SCHEMATIZATION

The modelling area is located in the eastern part of the Netherlands and covers 125 km^2 (see Fig. 3) Also shown is the area of main interest, the Lankheet estate, being approximately 5 km^2. The ground surface slopes from about 31 m above NAP (reference level in the Netherlands) on the east side to about 22 m in the west side. The difference in height of about 9 m means that weirs were constructed in the past to control the water level and flow. The area consists of sandy soils in the upper parts with some clay in the stream valleys. Land use is predominantly agricultural and forest. About 29% is in pasture, 10% is arable land, 55% woodland and 6% other.

For the SIMGRO model the groundwater system needs to be schematized by means of a finite element network. The network, comprising 16000 nodes, is spaced at about 25 m in the interest area and spaced at 300 m at the boundary of the model. For the modelling of the surface water the basin is subdivided into 990 sub-basins. The interaction between groundwater and surface water is characterized by a drainage resistance. This resistance is derived from hydrological parameters and the spacing of the water courses. The groundwater system in the model consists of a single aquifer with under laying Miocene clay. For the saturated zone the transmissivity varies between 25 and 300 m^2/d.

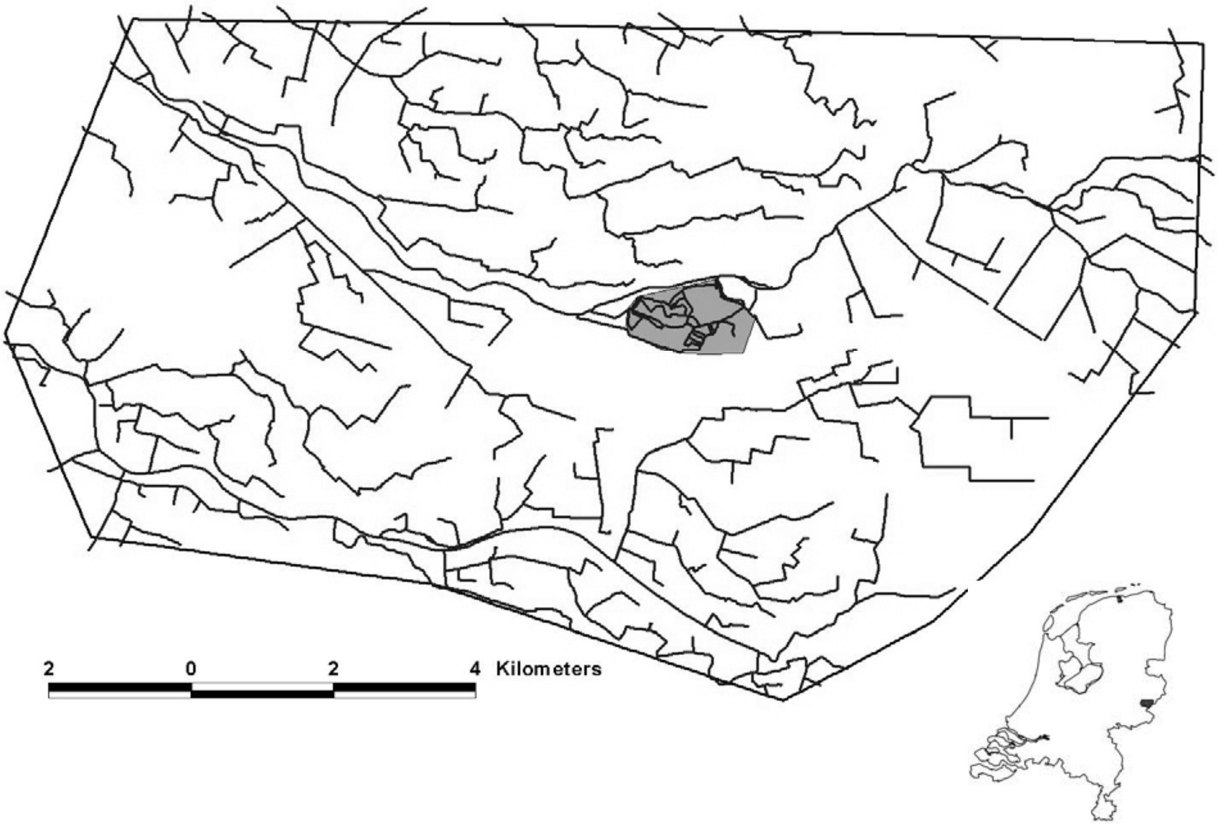

Figure 3. Location of the modelling area and the main water courses in the eastern part of The Netherlands. The shaded area is the Lankheet estate.

RESULTS

Running the model for the present situation and the climate change scenario gives differences in stream flows. For a closed sub-basin within the modelling area these are shown, for the years 1994 and 1995, in Figure 4, together with the change in stream flow. In winter the stream flow is higher, but in summer the flow is much smaller due to the reduced rainfall and the increased evapotranspiration. The dryer conditions in the climate change scenario results in higher water storage capacities in the ground, resulting in an attenuation of the stream flow.

The stream flows were also analysed in terms of frequency of exceedance, for the highest peak in this 5 year period the increase in flow was 15%. For 5 occurrences in this period the increase was 8-10%. In summer the low flow, Q95, occurring less than 5% of the time will be around 6 to 8% lower. Because of the relative short duration of the simulations (5 years) the calculations give a rough order of the changes in flow pattern, but a longer calculation period is needed to give a more precise answer. Simulations of basin response to climate change in the Netherlands reported some years ago (Querner 2002), gave increases in peak flows in the order of 20 to 30%, based on the previous set of climate change scenarios. In the present scenarios there is a lower increase in precipitation and the assumed evapotranspiration is higher.

For the extreme peak flow occurring in November 1998 it was estimated that the increase in flow for the climate change scenario lasted around 6 days and this increase was estimated for the sub-basin to be 4 mm of water. This amount of water can be retained in the reed fields and in the wet forest.

The effect of the climate change on groundwater levels in the modelling area was moderate. In summer the lowest groundwater levels, averaged over the 5 years, are in the order of 6-15 cm lower, and in winter the high groundwater levels around 5 cm higher.

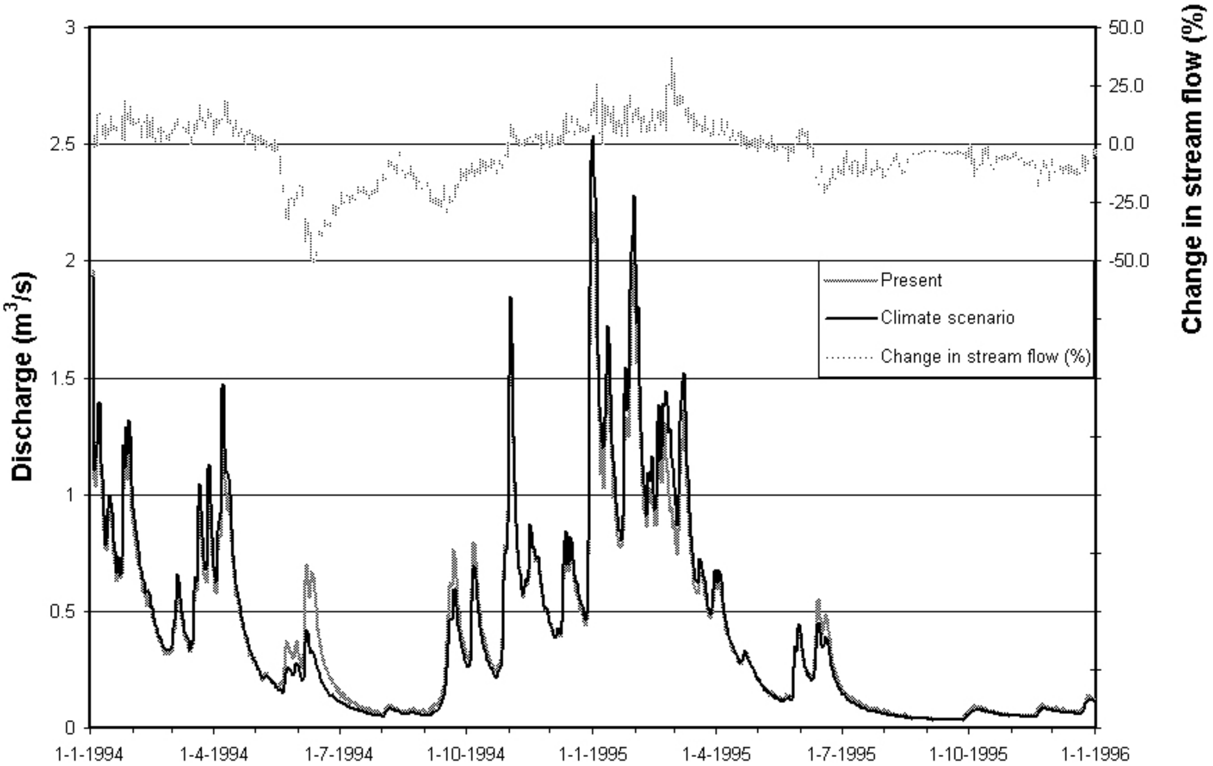

Figure 4. Effect of climate change on stream flow for a sub-basin of 31 km^2.

DISCUSSION AND CONCLUSIONS

The climate in Europe is expected to become warmer and wetter during the next century, the temperature rises, and stream flow from regional water systems reduces in summer, but peak flows in winter will increase. Therefore the anticipated climate change results in more frequent flooding and mitigation measures are necessary to cope with the hydrological risk. For the Lankheet region a scenario study was conducted to quantify the increased risk, using a regional hydrological model to simulate the groundwater flow together with the water flow in a network of water courses. The analysis shows that peak flows in winter will increase by 10 to 15%. The low flows in summer will decrease by 6 to 8%. This study shows that to adequately simulate the effect of climate change the model must be comprehensive and integrate surface water and groundwater, because the changes in precipitation and evapotranspiration will have a great effect on shallow groundwater conditions and on surface water levels.

The European Water Framework Directive can have enormous consequences for agriculture in the Netherlands. In parts of the country agriculture should be taken out of production because the nutrient loads to the surface water system are far too high. Using reed fields is a possibility to improve the water quality and these areas can be used as well for water retention in order to prevent flooding downstream. The analysis carried out gives knowledge on the multifunctional use of such a system and tools will be developed for the hydrological feasibility of water storage and purifying reed lands in other parts of the Netherlands.

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Recent trends in water discharges of Estonian rivers

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Keywords: climate change, runoff trends and long term variability of river discharges in Estonia

ABSTRACT

The runoff changes of Estonian rivers from the beginning of 20th century were analyzed using observed data and methods of empirical statistical analysis. The work was done in the format established by the Climate and Energy (CE) project, within the Statistical Analysis group, where the main objective was to find any signals of possible climate change in the historical hydrological time series. Previous national studies of the Nordic and the Baltic countries demonstrate that changes in annual streamflow were governed by changes in precipitation whereas trends in seasonal streamflow and extremes were largely influenced by changes in temperature. This might indicate that hydrological stream flow changes are influenced by climate changes in the Nordic and the Baltic countries. At the same time, hydrological trends vary between the regions and depend on not only local hydrological and hydrogeological factors but also on the selected period of trend analysis. Reference periods 1922-2003, 1941-2003 and 1961-2003(2004) were used in previous studies that did not characterize the natural hydrological cycles variability. Therefore, the main objective of the current study was to demonstrate how runoff trend results might differ when we compare climatological periods with periods of natural runoff variations. The study shows that the duration of the analyzed period is of extreme importance. The integral differential curve (ID) was used to determine more reliable periods of observational series that may characterize natural runoff variability. Because seasonal time series might be affected by human impact the annual average discharges were used for the ID curve analysis. The subdivision of streamflow time-series data by ID curve separated them into three homogeneous periods which are different from the standard climatological periods and the following results were obtained: i) runoff increased from the beginning of observation until 1932, ii) runoff decreased for the period 1932-1977 and iii) runoff increased for the period 1977-1992 with a more stable or slight decrease in flow after 1992.

INTRODUCTION

The global average surface temperature has increased during the past 100 years. About 0,5°C of the observed global mean warming has taken place during the last 30 years, with 11 of the 12 warmest years on record occurring in 1995-2006 (IPCC, 2001, 2007). Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. In the Northern Hemisphere, decreasing snow cover and land- and sea-ice extent are positively correlated with the temperature increase. The observed changes regarding hydrology (IPCC, 2001) are summarized, as: "There are apparent trends in streamflow volumes -increases and decreases- in many regions. However, confidence that these trends are a result of climate change is low because of factors such as the variability of hydrological behavior over time, the brevity of instrumental records, and the response of river flow to stimuli other than climate change." Nordic and Baltic countries are not an exception (Hisdal, 2006, Reihan *et al*, 2006). In general the changes in annual streamflow follow the changes in precipitation; however a shift in timing of high streamflow from spring to winter could be linked to the increase in temperature. The detected changes in climate and hydrology might vary considerably between regions and water resources managers want to know more about the future changes in order to mitigate measures for long-term planning and activity in water management.

The current study is done within the Climate and Energy project, where Nordic and Baltic countries study the impact of climate change on the hydropower sector. In the case of Estonia, it can be possible to link changes in stream flow records with changes in climatological parameters, however, these changes are varied across the territory mainly depending on river type feeding, geology, and the influence of the Baltic Sea. Even though the territory of Estonia is small, (45000 km^2) geographical location also plays a role. For example, in the north of Estonia spring and summer come 1-2 weeks later than in the south, summer is shorter and winter is longer. Climate changes in the coastal regions are more variable, for example, the beginning of winter in the coastal area compared with the inland regions can vary up to 5 weeks. As stated in Jaagus, 1998, and in Tarand *et al,* 2001, annual air temperature has increased about 1^{o}C during the past 150 years and the largest increase (about 3,6^{o}C) was observed in winter time. Annual precipitation has also increased about 50 mm during the same period, and the greatest changes were observed in the autumn and winter seasons. Investigation of trends of streamflow series in Estonia can be found in Reihan, (2002) and Reihan *et al.* (2006). The main objective of this paper is to investigate if streamflow changes in Estonia can be associated with changes in climate taking into consideration natural runoff variability. The following sections describe the data used, methods applied for selection of periods, trend results and conclusion.

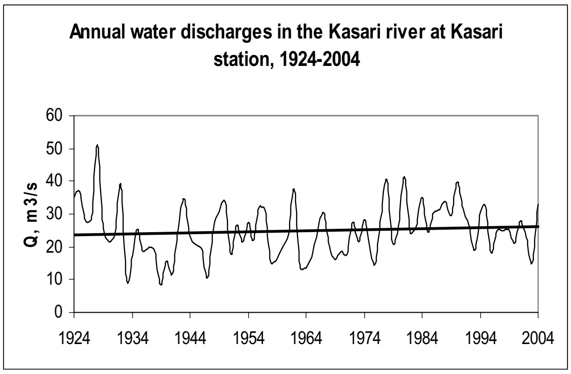
DATA AND METHODS

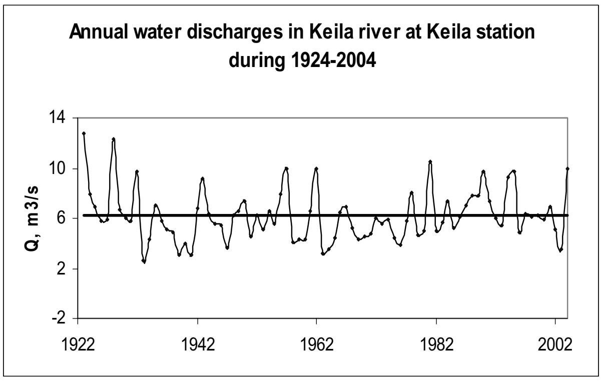
A total number of 7 meteorological stations with records of monthly temperature and precipitation data and 14 daily streamflow records were analyzed. The Estonian Meteorological and Hydrological Institute operate all of these stations. The criteria for selection of the stations were that the period of observation should be as long as possible, the human impact as small as possible and their spatial distribution should cover the whole Estonian territory. The duration of observations at the selected stations varies from 98 to 45 years and covers the period from 1903 to 2004.

There are many published case studies concerning methods to divide observational time series data to study the homogeneity of a series. For example, in Boden *et al.* 1990 it is shown that in 1930, the annual temperature anomalies change from positive to negative (1950-1979 was used as the reference period). In the Nordic and in the Baltic countries three periods: 1922-2003, 1941-2003 and 1961-2003(2004), which are commonly used for stream flow analysis (Hisdal, 2006, Reihan *et al.* 2006), were used as the reference periods. Because there is no exact opinion among scientists for what time period is necessary to divide observed hydrological time series data to evaluate the homogeneity of the series, trend analysis was done for the three homogeneous periods: from the beginning of observation until 1932, 1933-1977 and 1978-2004. These periods were selected by visual inspection in accordance with characteristic points on the integral differential (ID) curves: $\sum(Q_i - Q_0) = f(i)$, where Q_i is the annual water discharge for each year and Q_0 is the mean value of water discharge for the observational period. The duration of the selected periods varied by about 2-5 years for the different regions, however they show the natural runoff variability and effect of air temperature changes during those cycles. Even though the selected time series data were thought to be minimally affected by human impact, the longest series usually consist of different inhomogeneous forms, therefore for ID analysis only annual stream flow was selected. Homogeneity testing was done for the all analyzed time series of all hydrological and meteorological stations. The Standard Normal Homogeneity Test (SNHT) (Alexandersson and Moberg, 1997) was used. The Mann-Kendall test (the details of the theory are described in Gilbert, 1987) with a 5% significance level, which is a relatively robust method concerning missing data was applied for each data series at each site for trend analysis.

RESULTS

Previous study (Reihan *et al.*, 2006), where 1922-2003, 1941-2003 and 1961-2003(2004) observational periods were analyzed, showed that significant increasing linear trends of annual and winter seasonal runoff were dominating for the last analyzed period 1961-2004 for almost all analyzed stations. The same significant trend in winter air temperature and precipitation for the cold period after 1941 was found that caused an increase in annual and winter runoff. Seasonal spring, summer and autumn runoff and summer droughts has no trend. The same result was obtained in precipitation trends, however, the air temperature trend has a weak relation to seasonal runoff changes (this relation is stronger for summer and autumn seasons). The tendency for a decrease of spring floods was notable for the continental regions for all periods for 80% of stations. However for the coastal and transitional regions the last period does not have the same systematic pattern (Reihan *et al.*, 2006).





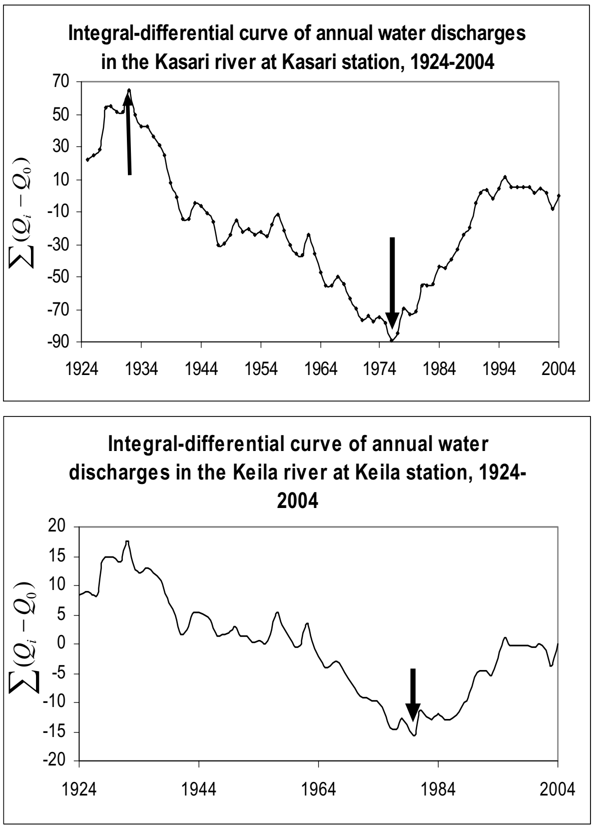
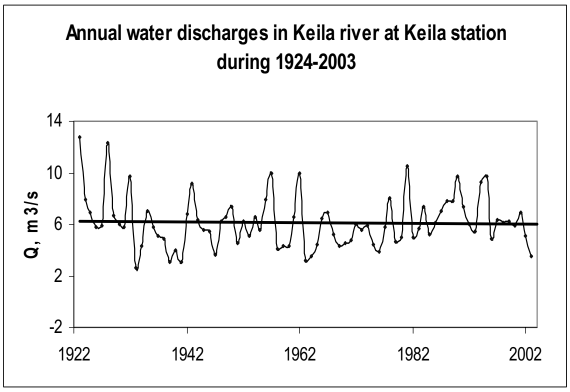


Figure 1. Chronological graphic (a) of annual water discharges with linear trend at two monitoring stations (Kasari, Keila) in the west- and north-west of Estonia; integral-differential (ID) curve (b) for the same stations during 1923-2004 (arrows show a sharp change in the curve direction).

As previously mentioned the duration of observations is very important. The time series data were divided into subperiods at a characteristic point on the integral differential curves. The results of homogeneity testing of the observed series on mean annual air temperature and runoff showed that for at least two of the selected periods for all stations the trends were significant at the 5% level. Statistically significant air temperature fall and rise were in agreement with changes in annual run-off. Runoff fall was observed for all stations for the period from the beginning of observation up to 1976 (1978) with a rise up to 2002. Fig 1 shows that annual stream flow trends increased in the Kasari river at Kasari station and in the Keila river at Keila station for the observation period of 81 years and 82 respectively. However, if the analyzed observational period for the Keila station were to end in 2003, one year shorter, the trend changes to decreasing (Figure 2) without any changes in integral curve oscillation.



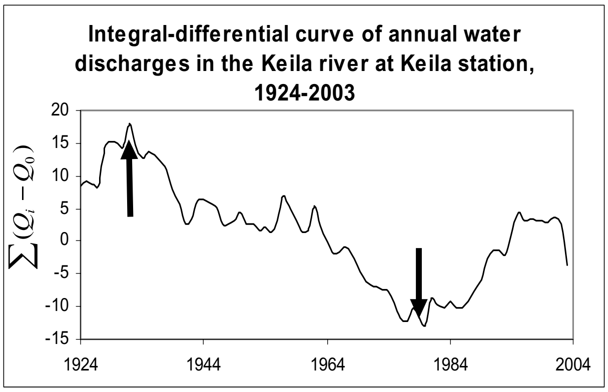


Figure 2. Variations of annual water discharges in the Keila river at Keila monitoring station during 1923-2003; 1) with the linear trend; 2) its integral-differential (ID) curve (arrows show a sharp change in the curve direction).

The next example from the north-eastern and eastern parts of Estonia is shown in Figure 3, where the observational period for the Vasknarva station in the river Narva starts in 1903. The Narva river hydrological regime is regulated by Lake Peipsi and is located in a region where human activity is very intensive. The trend analysis shows the decreasing of annual runoff that is different from trend in the western rivers, however the ID curve clearly demonstrates that points with sharp changes in direction are in agreement with the periods in the integral differential curve of the western rivers. Even though, the regional hydrogeological and climate factors are different the hydrological cycles are the same which could indicate the impact of climate on river runoff variability.

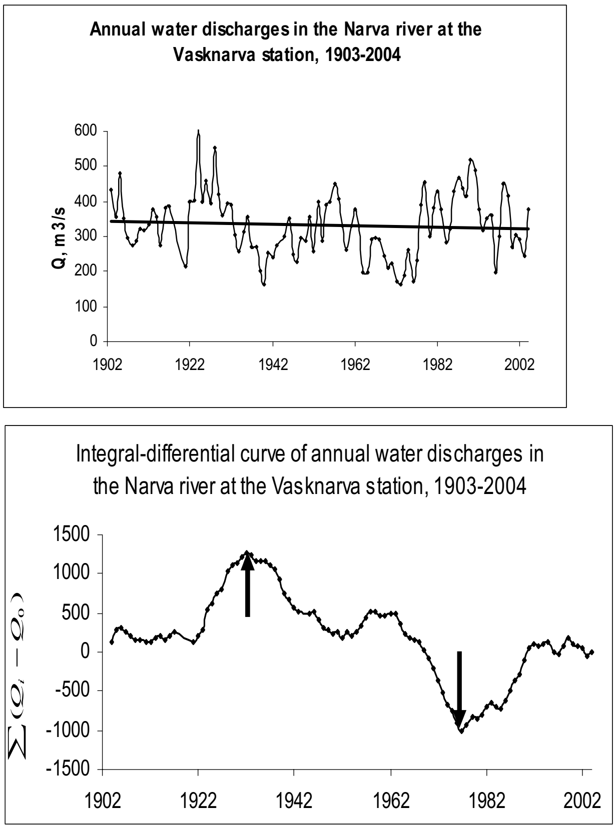


Figure 3. Variations of annual water discharges in the Narva river at Vasknarva monitoring station during 1903-2004; 1) with the decreasing linear trend; 2) its integral-differential (ID) curve that might be separated into three homogeneous periods: 1903-1932, 1933-1977, 1978-2004.

Analysis shows that the use of ID curves confirms the significance of the selected periods at the 5% level of significance for 70% of stations and for 40% if the observational series are divided into references periods used before. An example of the statistical analysis of observational series homogeneity for the Narva river is given in table 1.

Table 1. Mann-Kendall test results of the Narva river for different selected periods: 1903-2004, 1941-1960 and 1961-2004; 1903-1932, 1933-1977, 1978-2004

Periods (reference)	Tendency determined by linear trend	Significance level	Periods (ID curve)	Tendency determined by linear trend	Significance level
1903-2004	Decreasing	No (p=0,23)	1903-1932	Increasing	Yes (p=0,05)
1941-1960	Decreasing	No (p=0,09)	1933-1977	Decreasing	Yes (p=0,05)
1961-2004	Increasing	Yes (p=0,025)	1978-2004	Increasing	Yes (p=0,03)

CONCLUSION

The analysis of streamflow changes and the climate factors that affect these changes show different trends. The strongest relation between runoff and climate is found for the winter period. Statistically significant positive trends were found for spring air temperature; however, the relation with runoff changes is weak and could be explained by water infiltration into the groundwater. This study indicates that the use of ID curves makes it possible to take into account the natural runoff changes, i.e. to divide the observational series more reliably than using previously selected periods in accordance with the climatologically standard. It should be also noted that the natural runoff variability should be considered in streamflow trend analysis.

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Floods and droughts in a changing climate in Norway

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ABSTRACT

Projections of future floods and summer droughts are compared to the flood regime of the present climate for a number of Norwegian basins. The predictability of the flood and drought simulations are examined by comparing the statistical properties of control series, representing present climate with the observed flood statistics of the control period. The projections of future floods and droughts are based on daily series simulated by dynamical downscaling of the results of the global atmospheric circulation models ECHAM4 of the MaxPlanck institute driven by the SRES B2- and of the Hadley Am3H-model of the British Met.Office driven by the SRES A2 and B2 emission scenarios. The data have been adjusted to climate stations and were used to drive the hydrological model. Changes in the amount and duration of snow cover will result in shifts in the seasonality of floods. Large snow melt floods are likely to be less frequent late in the scenario period, but will occur early in the period because of increasing winter precipitation, accumulating as snow in mountainous basins. Rainfall floods are likely to be more frequent in a warmer climate, and the intensity will increase. The two models produce differences in the projected atmospheric circulation over Norway, with implications for the regional distribution of floods. Increasing discharge in the winter will reduce the severity of winter droughts, but earlier snowmelt and warmer summers with reduced rainfall can cause more severe summer droughts.

INTRODUCTION

Global warming of the surface temperature with approximately 0.6 °C has been observed during the last 100 years. Different climate change scenarios project a further increase of global temperature between 1 °C to 5 °C by the end of this century (Cubash et al., 2001). At the regional scale both increases and decreases in precipitation are projected, however, the projections of the development of precipitation are even more uncertain than for temperature (Benestad, 2006). Changes in the occurrence of floods and droughts in the Nordic countries have been examined both in historical series and in scenarios by Hisdal et al. (2006).

Historical information indicates a tendency to clustering of floods and droughts in certain periods characterised by temperature anomalies in Norway. Whereas large combined snowmelt/rainfall floods tend to occur before or after a sequence of very cold years, rainfall floods tend to cluster in warmer periods such as the 1930s and since 1987. Climate models indicate that the temperature will rise, most in the winter, and that intensive rainfall will be more common in some regions in the future climate. A reduced snow pack will lead to shifts in the seasonality of floods.

PRESENT FLOOD AND DROUGHT REGIMES IN NORWAY

Most Norwegian rivers have a dominant snowmelt flood occurring from late winter to early summer depending on the altitude of each upstream basin. Autumn floods occur mostly near the coast in East Norway and in West Norway and the southern districts of North Norway. Coastal basins can also have large winter floods caused by heavy rainfall in combination with snowmelt. Some very large rainfall floods have occurred in the late summer or early autumn. The largest historical floods have occurred mostly at this time of the year, either at the start or end of sequences of very cold years during the Little Ice Age (LIA). These events are caused by unusual circulation types, which may occur when the atmospheric circulation is shifting from one dominant mode to another. Local summer rainstorms causes flooding in smaller inland basins, most frequently in warm periods such as the 1930's and recently since 1987.

Low flows or droughts in Norway can be caused either by low precipitation often combined with high evaporation losses (summer droughts), or result from precipitation being stored as snow (winter droughts).

The economical consequences of flood and droughts can be substantial. The 1995-flood in eastern Norway cost 1.8 bill. N.kr. in damages. Since 1996 the cost associated with floods exceed annually all other damages caused by natural disasters in Norway. Much of this damage occurs in urban areas. Drought can also cause large costs and the 2002/2003 drought brought electricity prices to unprecedented high levels.

CLIMATE SCENARIOS

Results from the Max Planck Institute atmosphere-ocean general circulation model ECHAM4/OPYC3 (Roeckner et al., 1999), and from the general circulation model HadAM3H developed from the atmospheric component of the Hadley Centre atmosphere-ocean general circulation model HadCM3 (Gordon et al., 2000) have been used for assessment of climate change impacts on water resources in the Nordic countries. Observed fields of sea-surface temperature and sea-ice dataset were used as lower boundary conditions in the control simulation with HadAM3H (~1.875° by 1.25°, approximately 100 by 138 km^2 in the Nordic countries). In the climate change experiments, the sea-surface temperature anomaly described by HadCM3 was added to the observed data to be used as the lower boundary forcing. Assumptions about future greenhouse gas emissions were based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) A2 and B2 scenarios (Nakićenović et al., 2000). Up to 2100 B2 gives approximately 2.5 °C increase in global temperature while A2 is giving an increase of 3.5 °C. Scenarios based on a transient simulation of the earlier SRES IS92a for the period 1980 to 2049 were also used in simulating the discharge as basis for evaluation of the extremes in the nearer future.

The hydrological model utilises time series of daily temperature and precipitation data at a number of climate stations. Data was therefore downscaled to a 55 by 55 km2 grid by the HIRHAM model (Bjørge et al., 2000). Data was adjusted statistically from this grid to actual climate stations (Engen-Skaugen, 2007).

Series of daily discharge were simulated for the control period 1961-1990 and for three climate change scenarios based on the Gridded Water Balance (GRW) Model (Beldring et al., 2003) for the period 2071-2100. Discharge series have also been obtained based on the earlier SRES IS92a scenario for a transient simulation for the period 1980-2049 for selected basins.

PROJECTED CHANGES

The mean and standard deviation of the annual maximum flood were compared for the control run (1961-90) and the scenarios (2071-2100) for 22 basins in Norway. The statistics of the control run were also compared with the statistics of the observations for a subset of not regulated stations with data coverage for the control period. Flood frequency analysis has been applied to the annual as well as the seasonal maxima of the control and the scenario period for all basins to determine changes in the flood regime. Each series comprise of 30 annual values, and form the basis of the frequency analysis. Estimates of the 50-year flood were based on the General Extreme Value (GEV)-distribution estimated by the Probability Weighted Moments method (Hosking and Wallis, 1987).

Table 1 gives the mean annual flood (MAF) and standard deviation of the observations for seven selected basins in Norway. The MAF is generally underestimated in all control runs. The standard deviation is mostly underestimated, with some exceptions. The hydrological model generally simulates too low annual maxima. The lack of representativity of temperature and precipitation data is probably an important cause for the bias. The bias complicates the interpretation of the expected changes in annual floods and for floods of higher return periods.

Comparing the control-runs with the scenarios indicates that the MAF was reduced with 1 to 25% in inland and mountainous basins in eastern Norway with snowmelt dominated flood regime. All scenarios indicate an increase in the MAF in west Norway where floods are mostly caused by rainfall combined with some snowmelt late in the year. The scenarios indicate an increase of up to 40 %. Central and northern Norway has a decrease (2-9%) in the MAF based on the HadAm3H-model, but an increase (35-69%) in the ECHAM4 scenarios. This increase is largest in the southern part of northern Norway. The projected change in the 50-year flood was of the same magnitude as the change in the MAF.

Table 1. Mean and standard deviation of the annual flood in 7 basins in Norway for the observations, the control period and the scenario period.

		Observert 61-90	HadAm3H Control 61-90	HadAm3H A2	HadAm3H B2	ECHAM4 Control 61-90	ECHAM4 B2
Nybergsund Trysilelv	Mean	326	308	279	291	303	231
	Std.	121	131	113	117	74	97
Sjodalsvatn Sjoa	Mean	138	115	113	112	119	118
	Std.	49	33	27	32	40	30
Austenå Tovdalselv	Mean	73	62	59	64	59	63
	Std.	19	18	11	13	13	13
Stordalsvatn Etneelv	Mean	76	59	67	74	56	76
	Std.	21	12	18	13	14	14
Viksvatn Gaular	Mean	181	179	211	234	180	232
	Std.	32	50	50	52	52	49
Nervoll Vefsna	Mean	207	156	141	150	155	157
	Std.	43	33	27	32	38	24
Masi Alta	Mean	512	662	564	501	625	615
	Std.	258	171	178	179	180	200

The winter floods (djf) were projected to increase (10- 300%), most in mountainous and inland areas where the winter floods are low or almost absent in the climate of the control period. Multiple warm spells will cause multiple minor floods during the winter in the lowlands. The spring floods (mam) were projected to increase (10- 110%) in mountainous areas and decrease (5- 40%) elsewhere. The summer floods (jja) were projected to decrease by (20- 60%) except in three basins in the southwest, while the autumn floods (son) will increase (5- 90%) according to the ECHAM4 scenario and decrease (0- 40%) in most basins according to the HadAm3H scenario. Figure 1 gives the percentage change of the annual and seasonal 50-year flood of three selected basins in Norway.

Figure 2 show estimated annual flood values for two alpine basins in southern Norway based on the transient run 1980-2049. The experiment was also run for a control period 1980-99 and 2030-49. By comparing the 50-year return period calculated from the two time slices, an increase (9%) has been found. By calculating the 50-year return period flood of all possible 20-year time slices the change can be as high as 50% in the slice with the largest floods. This demonstrates the importance of natural variability. The change and pattern towards a clustering of extremes are similar is of the same as seen from observed data based on a time slices as short as 20 years.

The summer drought duration was defined as the maximum number of days below the 70 exceedance percentile, Q_{70}. Q_{70} and the maximum drought duration were compared in the control run and the scenarios to determine the change in the drought duration. Roald et al. (2006) has shown that the summer flow will decrease in much of Norway and that the maximum soil moisture deficit will increase in the future. The 70 percentile show a general decrease in the same areas. The maximum drought duration increased in 56% of the basins and decreased in 36%.

DISCUSSION

The most pronounced effect of floods in a warmer climate is the shift in the seasonality caused by more rainfall and gradually reduced snow storage as the temperature increases. The winter precipitation is projected to increase, with possibly increasing snow storage in mountainous districts early in the scenario period. The duration of the snow cover will decrease, and the peak of the snowmelt will occur earlier. The spring flood will shift from the early spring to the late winter in lowland basins and from the summer months to the spring in mountainous basins. Earlier spring snowmelt floods is already observed in the Nordic region (Hisdal et al., 2006) and this has implications also for the summer droughts. As the summer season is extended in a warmer climate and many scenarios in addition predict less precipitation in the summer season, the probability of longer summer droughts increases.

Intensive summer rainstorms are local phenomena, and the resolution of the climate model is far to coarse to model these events. Historical data from Norway show that intensive summer rainfall floods occurs far more frequently in warm periods, such as the 1930's and since 1987, than in colder periods. These events can trigger landslides, and represent a hazard that can increase especially in steeper terrain or in lowland areas susceptible to quick clay slides. Urban flooding is also a result of intensive rainstorms.

The regional distribution of precipitation in Norway is strongly dependent on the trajectories of the precipitation areas because of the Norwegian topography (Tveito and Roald, 2005). The HadAm3H and the ECHAM4 scenarios indicate a somewhat different atmospheric simulation over Norway. The ECHAM4 scenario indicates increasing westerlies and more precipitation in western and northern Norway, while the HadAm3H scenario indicates more precipitation from the east and less precipitation in coastal basins in central and northern Norway. This has implications for both floods and droughts in the scenarios.

The use of time slices of 20 or 30 years are very short when assessing possible changes in the occurrence of future floods and droughts, because of the high natural variability in historical flood and drought series. Land use changes especially development of flood plains and urbanisation can cause changes in the risk of flood damage which by far exceeds the changes induced by climate change.

CONCLUSIONS

The bias in the flood statistics of the simulated and observed data series makes the evaluation of floods in a future climate based on scenarios difficult. The projected temperatures are however less uncertain than the projected precipitation. The temperature control the accumulation and melting of the snow and controls thus the timing and magnitude of the spring flood. The flood magnitudes are therefore expected to decrease in inland basins in eastern Norway, where more severe summer droughts are expected. The flood magnitudes are expected to increase in western Norway, while the scenarios diverge between the two climate models in central and northern Norway. The winter floods will generally increase and become more frequent, the spring flood will increase in the mountains, and decrease elsewhere, the summer flood will decrease almost everywhere and the autumn floods will increase in most regions.

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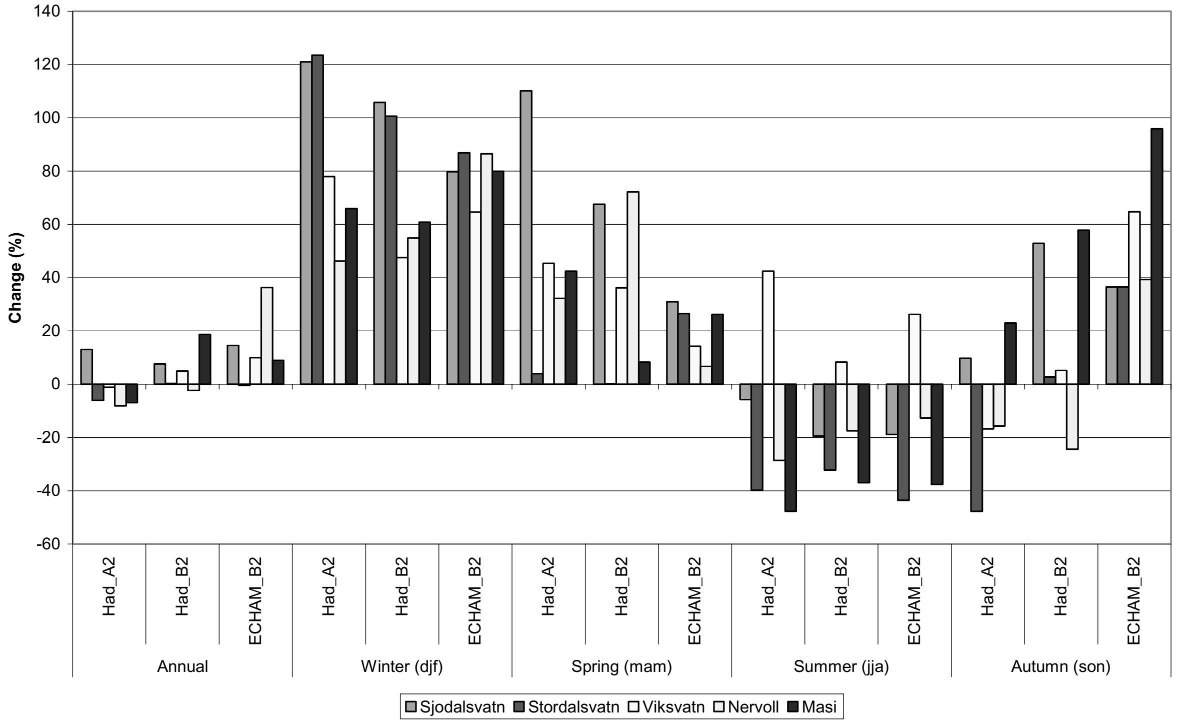

Figure 1. The percentage change in the annual and seasonal 50-year flood for scenarios based on the HadleyAM3H- and the ECHAM4- model is shown for 5 basins. Sjodalsvatn is in the alpine area of eastern Norway, Stordalsvatn is a coastal basin and Viksvatn a more mountainous basin in western Norway, Nervoll is in the southern part of north Norway and Masi is an inland basin in Finnmark further north.

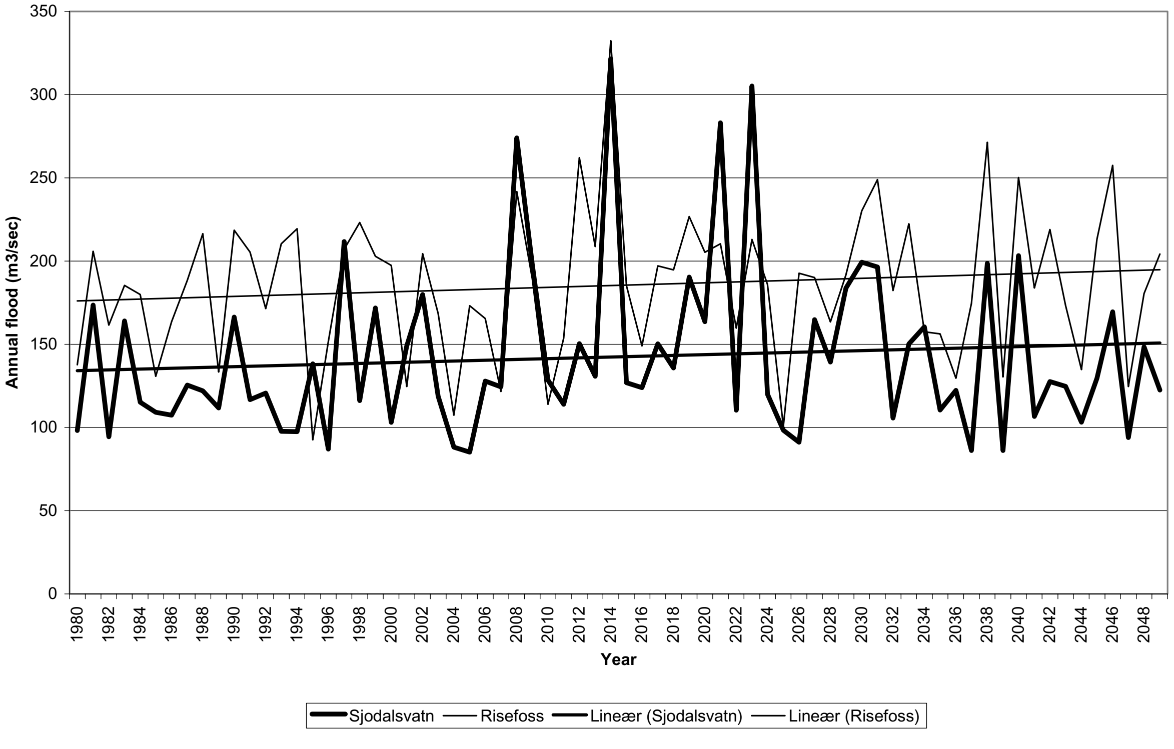

Figure 2. Annual floods at Sjodalsvatn in Jotunheimen and Risefoss in Driva simulated for the full transient period of 1980-2049 based driven by data series downscaled from a transient run of the ECHAM4-model and the emission scenario: SRES IS92a.

Alternative Irrigation Development Paths in an Uncertain Climate: Farmer-Initiated Irrigation Development in Northern Ghana

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ABSTRACT

Irrigated agricultural development is extremely limited in Sub-Saharan Africa, contributing to low levels of agricultural productivity. Climate change is anticipated to exacerbate low productivity in rainfed agriculture within the region, via increased evapotranspirative demand and unpredictable alterations in precipitation patterns. Irrigation development is viewed as an effective strategy to increase agricultural productivity and food security; and as an adaptive strategy to the impacts of global and regional climate change. However, expansion of irrigation will result in a reduction in water supply available for other purposes, such as municipal, domestic and industrial use, hydropower generation and environmental flows. This study is a preliminary examination of the potential impacts of expansion of three small-scale irrigation technologies – small reservoirs, shallow groundwater and riverine pump irrigation, respectively – within the White Volta Basin in Ghana and Burkina Faso, West Africa. Results indicate that under reasonable assumptions concerning the expansion of irrigated area over the period 2000 – 2040, flows on the White Volta will be significantly reduced, likely affecting hydropower generation capacity downstream. Impacts will be particularly acute assuming Ghana's UNFCCC climate change projections.

INTRODUCTION

The irrigated agricultural situation throughout much of Sub-Saharan Africa (SSA) presents a paradox: Climate is characterized by strongly seasonal rainfall, high potential evapotranspiration (ET0)-to-precipitation ratios and considerable inter-seasonal and interannual variation in rainfall and soil moisture. Nevertheless, investment in supplementary irrigation (and water management infrastructure in general), which would mitigate the impacts of difficult climatic conditions on rainfed agricultural productivity, remains at very low levels throughout the region (FAO 1986; FAO 2007). Considerable research has been directed toward underlying causes, and program and policy design to accelerate the expansion of irrigation within the region. The emerging consensus that climate change will be largely antagonistic toward food security goals within SSA adds a degree of urgency. However, it is also imperative that the aggregate consequences of irrigation development in SSA be viewed within the overall framework of water resources supply and demand, as growing population, shifting economic priorities as well as climate change itself present new challenges to water resource management within African river basins. We present a preliminary examination of the potential impacts of irrigation expansion within the White Volta tributary to the Volta Basin in West Africa. It is supported by modeling studies conducted by the GLOWA Volta Project (GVP), a 9-year study of climate change and the hydrologic cycle within the Volta Basin, an important international basin encompassing much of Ghana and Burkina Faso. The Volta Basin presents an unusual challenge in water management, since irrigated agriculture, the major (and growing) abstractive use of water, occurs largely upstream of the Basin's primary storage complex, Volta Lake and Akosombo Dam. This dam and reservoir have been developed primarily for the generation of hydro-electric power, which currently serves as the primary source of power for the entire nation of Ghana. Any activity occurring upstream of Akosombo that reduces Volta River discharge effectively competes with power generation for available water supplies. Even in the absence of extensive irrigation development in the upper Volta Basin, annual flows into Volta Lake have become increasingly erratic, leading to rolling power shortages throughout Ghana, occurring most recently in 2006-2007.

METHODS

Analysis conducted to date by GVP confirms several long-term trends in climate, hydrology and land use: first, an overall warming of the Volta Basin region, second, a delay in the onset of seasonal rains and finally, an ongoing conversion of land from non-agricultural to agricultural uses. Jung (2006) has generated linked climate-hydrology scenarios through 2039 using the mesoscale climate model MM5 linked to the physically based, distributed parameter hydrological model WaSim ETH. MM5 dynamically down-scales GCM (ECHAM4) outputs to 9 km x 9 km resolution over the Volta Basin region, and supplies boundary conditions to WaSim ETH, run at 1 km x 1 km resolution

The research we present is intended to evaluate the potential impacts of long-term development of irrigation on inflows into Lake Volta. We focus on three common, emerging small- and community-scale irrigation approaches: small reservoirs, shallow groundwater irrigation and riverine pump irrigation. To date, irrigation investment in these areas has reflected localized decision-making, taken with minimal concern over "downstream" impacts. Little is thus known about the aggregate or composite impacts of introducing large numbers of small reservoirs, or many hundreds (thousands) of hectares of shallow groundwater irrigation, on downstream flow regimes, and corresponding impacts on aquatic ecosystems, fisheries and related components of the flow system.

The White Volta Catchment, a sub-basin of the Volta basin (400,000 km^2) in Sub-Saharan Africa (SSA), is approx. 110,000 km^2 in area. It originates in the north of Burkina Faso and flows south-eastward to the border with Ghana. Mean temperatures range between 27 and 36 degrees. Annual precipitation ranges from around 1100 mm in Northern Ghana to as little as 300 mm in the upper reaches of the basin, 80% of which occurs from July through September. Potential evapotranspiration is between 2000 and 2500 mm annually. The majority of the region's inhabitants are rural, and small-scale rainfed agriculture is the primary economic activity. Agricultural productivity is low, at roughly 1 metric ton of cereal per hectare, reflecting erratic and unreliable precipitation and low levels of fertilizer consumption - less than 3 kg N per ha in Ghana, far below the world average of nearly 100 Kg/Ha.

RESULTS

Irrigation in the Volta Basin

Given the extreme annual distribution of rainfall in the Basin, irrigation development is seen as an obvious strategy to increase agricultural productivity and food security; and as an adaptive strategy to the impacts of global and regional climate change. Supplemental irrigation is clearly effective in increasing yields relative to rain-fed cultivation, and induces a "virtuous circle" whereby improved reliability in water supply encourages small farmers to invest in improved seeds, cultivation practices and inputs, such as high-nitrogen fertilizers. Each contributes further to improved yields, and to improved household income. Irrigation investment may in addition create or expand rural employment opportunities and diversify rural livelihoods. Given these potential benefits, it is surprising that irrigation in SSA, and within the Volta Basin, remains relatively undeveloped. Table 1 provides a summary of the irrigation sectors of Ghana and Burkina Faso, respectively, the two most important Volta riparian states. Less than 1% of cultivated area is currently irrigated, and only 1.6% (Ghana) to 15% (Burkina Faso) of potentially irrigated area is currently developed. Development authorities within the region currently emphasize community-scale and farmer-initiated irrigation strategies; many based on traditional methods of irrigation and water harvesting. Small-scale, community-developed schemes include (i) small reservoirs, (ii) shallow groundwater and (iii) riverine pump irrigation. Each is characterized by relatively low per-hectare development costs, and scales of operation consistent with decentralized management. The long-term viability and sustainability of such practices, viewed at aggregate or regional level, have not been established.

Table 1. Irrigation Development in Ghana and Burkina Faso

Variable:	Unit	Ghana	Burkina Faso
Total area	1000 ha	23,854	27,400
Arable land	1000 ha	4,185	4,840
Permanent crops	1000 ha	2,200	60
Average precipitation in depth	mm/yr	1,187	748
Total internal water resources per capita	m3/ca/yr	1,388	906
Agricultural water withdrawal	109 m3/yr	0.652	0.69
Irrigation potential	1000 ha	1,900	165
Area equipped for irrigation	1000 ha	30.9	25
Area equipped for irrigation as % of irrigation potential	%	1.63	15.15
Agricultural water managed area: total	1000 ha	30.9	46.4
Area equipped for irrigation as % of cultivated land	%	0.49	0.53

Irrigation Development Options

Small Reservoirs: Several hundred small dams have been constructed within the White Volta catchment over the last 4 decades by Government agencies and NGOs. These multipurpose structures consist of earth-fill dams 2.5 - 10 m in height and 100-750 m in length with passive spillways, storing maximum volumes of $10^4 – 10^7$ m^3 and serving irrigation perimeters of between 5 and 20 Ha (LACOSREP, 2004), that are equipped with small networks of distribution channels. Transient rainy season runoff from small catchments is impounded to provide seasonal storage for small-scale irrigation and water for domestic purposes, livestock and aquiculture. The reservoirs begin filling with the onset of seasonal rains, provide supplemental irrigation during the rainfed cropping season (April - September) and primary water supply during the dry cropping season (October – February). In many locations, these reservoirs are completely dry prior to the onset of the following year's rains. Low-relief terrain settings dictate that these reservoirs typically possess high surface area-to-volume ratios, leading to high evaporation rates. Numerical simulation suggests that evaporative losses can easily exceed potential withdrawals for irrigation. Additionally, reservoir siltation due to erosion within reservoir catchment areas can lead to significant reductions in storage capacity over relatively short time spans, necessitating premature rehabilitation.

Shallow Groundwater: The use of hand-dug shallow wells and dugouts for irrigated production of vegetables and cash crops has expanded as it has been shown to enhance income for farmers, and reduces development, coordination and management efforts that characterize formal irrigation. Shallow wells, typically a few meters in depth, are distributed throughout the White Volta catchment and are assumed to intersect shallow alluvial aquifers, that. These can be alluvial deposits associated with presently active stream courses, ocurring either in the channel or beneath the flood plain, which are saturated and are regularly recharged either by perennial stream flow or by annual flood waters. Groundwater is used preferentially for rural domestic water supply. Strategies promoting groundwater irrigation must therefore be evaluated carefully to eliminate the possibility of conflict with critical domestic uses.

Riverine Pump Irrigation: The recent introduction of low-cost, high-capacity pumps of Asian manufacture has created an interest in direct pumping of water from the main river corridor for floodplain irrigation. Dry season pump irrigation has only recently become practicable due to the opening of Bagre Dam in southern Burkina Faso, which ensures a minimum rate of discharge throughout the dry season from hydropower production. Irrigation is supplied to mango orchards, which also serve to stabilize the banks; and to tomatoes and other dry-season crops planted 20-30 m from the channel. Pumps often sit on floating platforms to accommodate variation in river stage, and water is delivered directly to field channels via pressure conduit. One pump can supply 5-8 Ha, often shared by 4-5 farmers. Farm trials by MoFA suggest that this cropping pattern has the potential to substantially raise the agricultural income of local farms and will therefore considerably contribute to food security and poverty reduction in one of Ghana's most poverty-stricken areas. However, this approach is raising concern among water resource managers, particularly, the Water Resources Commission (WRC) and the Volta River Authority (VRA), with regard to the impact of such activities on inflows to the main Volta dam for hydro-power generation.

Sustainable expansion of irrigation within the basin will depend extensively on physical (technical) efficiency. Irrigation efficiency is defined here as the ratio of water utilized beneficially (evapotranspired) by crops to total abstractions from surface- and groundwater sources. Historically, larger reservoir-gravity systems within the basin have performed at low efficiency. Mdemu (2007) has estimated gross efficiency at less than 20% (3,300 mm delivered at scheme level to support 560 mm of ET demand) on the Tono system in the Upper East region (UER) of Ghana, improving slightly when it is noted that roughly 500 mm are returned to the flow system via drainage. Small-scale systems are anticipated to operate at higher levels of physical efficiency.

Small reservoirs: Faulkner (2006) calculated the Relative Water Supply (RWS) for two representative small reservoir – irrigation systems in the UER (Tanga, Weega) through detailed water audits. RWS is the inverse of efficiency as defined above: (total supply/evapo-transpirative demand). Faulkner's (2006) supply term included direct precipitation, groundwater abstraction and surface (reservoir) irrigation. Only reservoir releases were included in the irrigation term, and changes in soil moisture over the study period were included in supply calculations. Crop water demand was calculated to be in the range of 4 to 6 mm per day during the dry season in this region. Faulkner (2006) estimated RWS to be 2.4 at Weega, and 5.7 at Tanga, the differences relating primarily to management. These numbers, particularly at Tanga, are not significantly better than scheme-level efficiency as measured at Tono (Mdemu, 2007). Analysis of overall efficiency of small reservoirs as irrigation supply must also include direct evaporation from reservoir surfaces. Data on roughly 80 small reservoirs recently rehabilitated in the UER was obtained from LACOSREP (2004). For 56 of these reservoirs, data on both irrigated perimeter and maximum extent of reservoir surface area were available. The mean ratio of maximum reservoir surface area to irrigated command was found to be 1.53. Simulation modeling of small reservoir-irrigation systems in the UER indicated that a typical small reservoir system operated primarily for irrigation supply will evaporate 1,360 mm per year per Ha of maximum (full) reservoir surface area. Thus, the total water requirement for small-reservoir irrigated systems can be approximated at 4 times the direct (beneficial) evapo-transpirative demand (average Weega, Tanga RWS); and an additional 2.0 Ha-meters per hectare of irrigated perimeter.

Shallow Groundwater: Shallow groundwater irrigation is a high efficiency form of irrigation, since water is withdrawn from wells and applied directly to the raised plant bed, typically by bucket or watering can. Physical efficiency is here assumed to be close to 1.0 – all water applied is used for beneficial crop evapotranspiration. Tomatoes and peppers are important groundwater-irrigated dry season crops in this region. Mean seasonal applications, derived from precise bucket-counts and plot measurements, average 400 mm per season for tomatoes and 380 mm for peppers.

Riverine Pump: GVP, in collaboration with the Ghanaian Ministry of Food and Agriculture (MoFA), has initiated a study within the White Volta in Ghana. Total discharge from each pump will be measured by current meter. Since pressure conduit is used to convey water to field channels, conveyance and distribution efficiency should be high. We assume here that overall scheme efficiency is around 90%.

To provide a first-cut estimate of the impacts of irrigation expansion, we examine three scenarios for the White Volta Basin over the period 2000 – 2040. The first assumes no changes in climate or hydrology, and examines the implications of growth in irrigated area, by type. The second is based on the GVP coupled MM5-WaSiM climate & hydrology simulations, specifically the changes between "present climate" (1991-2000) and "future climate" (2030-2039) simulations. The third, representing a more pessimistic future, reflects Ghanaian Government projections of climate and hydrology associated with global climate change (Figure 1).

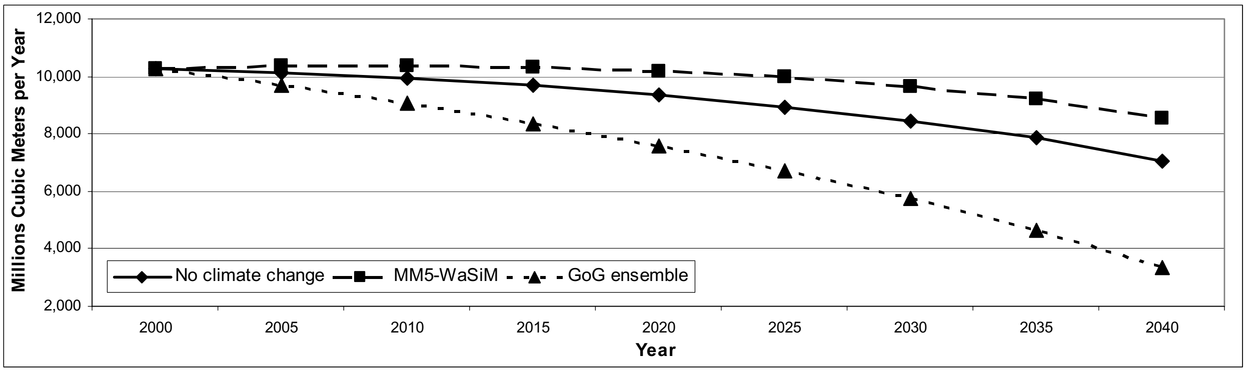

Figure 1. Flow Reductions on White Volta (Nawuni) due to Irrigation Development and Climate Change

DISCUSSION AND CONCLUSIONS

Topography and soils will ultimately determine the feasible extent of each irrigation type. To provide preliminary estimates of the impacts of irrigation expansion on basin water resources, we make the following assumptions: (i) ca. 2000, there are 10,000 - 15,000 Ha under small reservoir irrigation within the White Volta. Between 1984 and 1999, area irrigated by small and medium irrigation systems grew by almost 15% per year. It is likely that topography and soils will limit potential to around 100,000 Ha. We assume that small reservoir-irrigated area expands by 5% annually over the period 2000 – 2040, from a base of 12,500 Ha. (ii) the present extent of shallow groundwater irrigation is unknown, since the practice is not documented by Government agencies. We assume that 2,500 Ha are currently irrigated seasonally by shallow groundwater, and that this will increase by 5% annually. (iii) Riverine pump irrigation is a relatively recent development within the basin, and its potential is restricted to favorable terrace and floodplain locations. MoFA has estimated the potential to be around 10,000 Ha within Ghana. We assume that a similar potential exists below Bagre dam in Burkina Faso. Pump irrigated area is assumed to be 2,000 Ha ca 2000, roughly half each in Ghana and Burkina Faso, and growing at 10% annually.

Climatic and hydrologic changes within the White Volta Basin, as simulated by the GVP model ensemble, are not anticipated to be profound over the projection period 2000 – 2040. The ECHAM4 BAU is used as the basis for dynamic down-scaling within MM5, coupled in turn with WaSiM ETH at daily timesteps. Two 10-year simulations were generated: "present climate" (1991-2000) and "future climate" (2030-2039). Projected changes are based on a comparison between "future" and "present" timeslices. For the White Volta within northern Ghana and central Burkina Faso, simulated potential evapo-transpiration increases by 9% over 2000 – 2039, largely reflecting temperature increases. This change is used to adjust crop water demand upward. MM5-WaSiM also simulates an increase in White Volta discharge at Nawuni Gauge of 14%. This reflects slight increases in simulated precipitation, increasingly in high-intensity events. The Government of Ghana bases their climate change scenarios on an average of three GCM outputs, HADCM$_2$, UKTR and UKHI (UNFCCC, 2001). They make the following projections for 2020 and 2050: (i) a 16% reduction in White Volta discharges by 2020, and a 37% reduction by 2050. (ii) analysis of changes in agricultural water demand focuses on rain-fed cropping systems, and hence on simulated changes in rainfall and temperature, but the increases in evapo-transpirative demand are imputed to be 5% by 2020, and 17% by 2050, respectively.

The composite results of these trends are plotted in Figure 1, showing the simulated discharge of the White Volta at Nawuni Gauge. The simulated "present" flows of around 10 BCM are in good agreement with historical gauging records for 1991-2000. Growth in small-scale irrigation within the basin alone is projected to reduce flows by roughly 30%, or around 3.2 BCM, between 2000 and 2040. Under GVP climate change scenarios, this is reduced to around 17% (1.75 BCM), reflecting the simulated increase in White Volta discharge under a changing climate. Using the Government of Ghana's (GoG) climate change scenarios, however, White Volta discharge is reduced by almost 70% (6.9 BCM), due both to simulated reductions in flow and to irrigation development (30%, or 3.2 BCM each). Even the most benign of these changes in flow regime will put pressure on downstream hydropower generating capacity, however, as the White Volta historically provides around 30% of the 35 BCM of annual inflow to Volta Lake.

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Temperature and precipitation projections for Finland based on climate models employed in the IPCC 4th Assessment Report

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Keywords: multimodel projections, global climate models, temperature, precipitation, Finland.

ABSTRACT

According to simulations performed with 19 global climate models, by the end of this century, annual mean temperature and precipitation in Finland are projected to increase by 3-7_C and 13-26%, respectively.

These figures only include the uncertainty due to future greenhouse gas emissions; in addition to that, projections given by the various models diverge quite a lot. Both the warming and the precipitation increase are stronger in winter than in summer.

INTRODUCTION

Temperature and precipitation projections composed for Finland were based on simulations performed with 19 global climate models (GCMs). These models belong to the set of GCMs employed by IPCC (2007) in composing the global-scale projections published in the 4th assessment report. The GCM data was downloaded from the CMIP3 data archive.

For the SRES A1B, A2 and B1 scenarios (the definitions of the scenarios are given in IPCC (2007)), simulations are available for most of the models. For the remaining three scenarios (A1FI, A1T and B2), no simulations have been performed. Surrogate data for the non-existing model simulations have been produced by applying a pattern-scaling method (Ruosteenoja et al., 2007).

All projections to be presented in this paper are area-means calculated over the entire Finland.

CLIMATE PROJECTIONS

Annual mean temperature and precipitation, averaged over the 19 GCMs, were found to increase virtually monotonously during the 21th century (Fig. 1). Up to year 2040, all the six SRES scenarios studied (A1B, A1FI, A1T, A2, B1 and B2) yield quite similar projections. In the second half of the century the projections diverge markedly. In the 2090s, the best estimate for the temperature response to the high-emission A1FI forcing is about 7 degrees, that to the low-emission B1 forcing being slightly over 3 degrees. Accordingly, the warming projected for Finland is nearly double the global average.

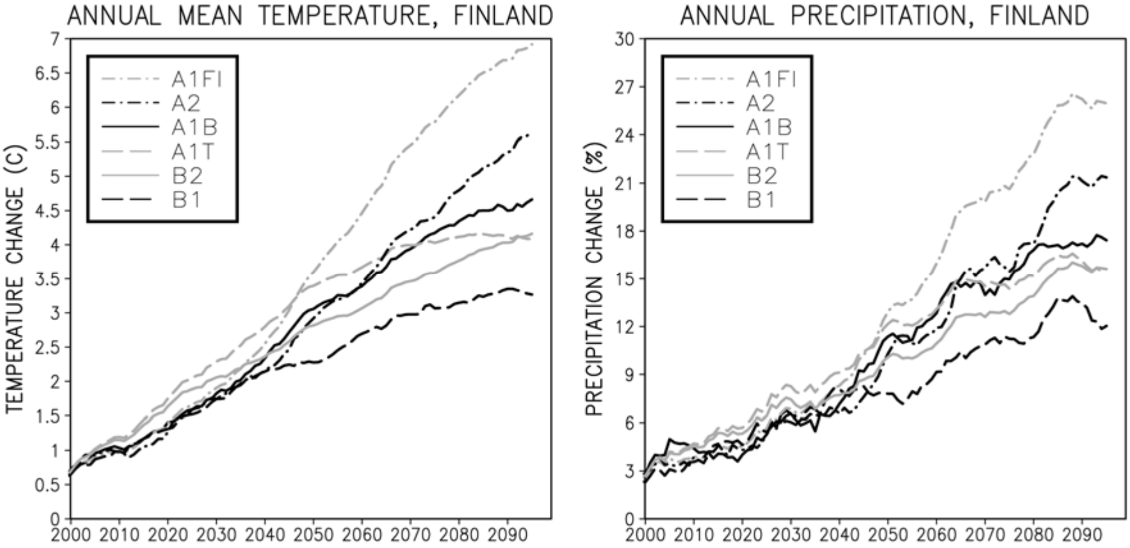

Figure 1. Projected changes of the annual mean temperature (left panel, unit _C) and precipitation (right panel, unit %) in Finland during the 21th century. Shown are the means of the estimates given by 19 GCMs, and the projections are presented separately for six SRES forcing scenarios (see legend). All changes are expressed relative to the mean of the baseline period 1971-2000. Curves have been smoothed by applying nine year running means. For the precipitation increase, the corresponding projections for the A1FI and B1 scenarios are about 26% and 13%, respectively.

Temperature increases much more in winter than in summer. If the A2 scenario materializes and the period 2070-2099 is considered, for instance, the best estimate for the temperature increase is 7.6 degrees for January and 3.3 degrees for July (Fig. 2, left panel). Correspondingly, precipitation is projected to increase about 30% in winter, about 10% in late summer (Fig. 2, right panel). However, there is quite a large scatter among the projections simulated by the various models. For example, in Fig. 2 the 90% probability interval for the January mean temperature increase is 5.3 to 9.8 degrees. Furthermore, it is virtually certain that precipitation will increase in winter, but for summer some models project even a reduction of precipitation.

DISCUSSION

The present temperature and precipitation projections were compared with the corresponding estimates inferred from simulations with six GCMs, participating in the previous IPCC assessment cycle (Ruosteenoja et al., 2005). Updated temperature projections differed little from the previous estimates, there being slightly more warming in winter and slightly less in summer. As far as the best estimate is considered, precipitation is now projected to increase in all seasons, while in the previous estimates precipitation remained nearly unchanged in late summer months. Moreover, in the new set of models the scatter among the precipitation simulations is somewhat smaller than previously.

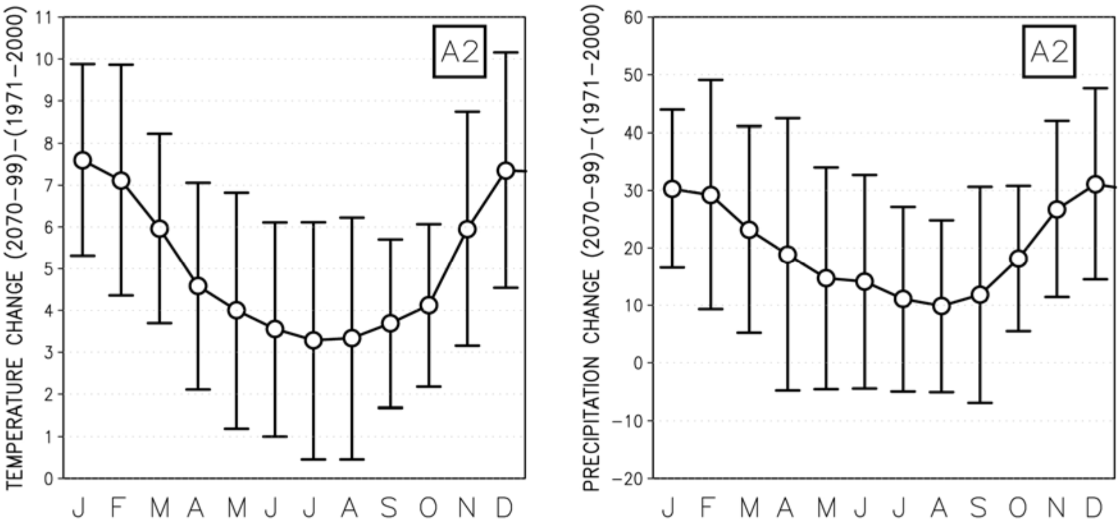

Figure 2. Temperature (in _C, left panel) and precipitation (in %, right panel) responses to the SRES A2 forcing in Finland for each month of the year. Means of the responses simulated by the 19 GCMs are denoted by open circles, 90% probability intervals (mean ±1.645× the standard deviation of the simulations) of the change by vertical bars. All changes are given for the period 2070-2099, relative to the baseline period 1971-2000.

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Climate change and water resources in the Aral Sea basin (Central Asia): questions requiring a scientific substantiation and prime attention

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Keywords: Central Asia, global warming, mountain glaciers, water resources, uncertainties

ABSTRACT

According to various Climate Change models, global air temperature's increase (GATI) is expected in limits 1.4-5.8 °C to 2100, in comparison with 1990. For practical purposes the gradation of GATI consequences is of interest from positions of their importance.

Below an attempt on estimation of basic consequences of GATI for water resources (WRs) in Aral Sea Basin (ASB) is undertaken, and questions are considered, which require more precise interpretation. Largest rivers of the ASB are Amudarya and Syrdarya. In the ASB nearly 116.5 km^3 of WRs are formed, from which in the Syrdarya river basin (RB) – 37.2 km^3, Amudarya RB – 79.3 km^3.

Accounts on Regional Climate Change models (RCMs) have shown that in the ASB:

- During the nearest 25 years essential change of WRs will not take place, in the Amudarya RB their reduction is expected 2-4 %, Syrdarya RB – they are increased on 3-4 %. WRs' changes are less, than error of river flow's (RF) measurements. Therefore regional RF's changes will not affect essentially on water allocation between Central Asian States. At the same time, in the relatively small RBs sharper fluctuations of RF are expected. For example, in the Chirchik-Akhangaran RB (Uzbekistan, Tashkent oasis; watershed area - about 22 000 km^2) the RF's changes can make: increase up to 6-8% (Chirchik river) and reduction up to 6% (Akhangaran) for vegetation period.

Seasonal RF's dynamics will change considerably, and repeatability of the high water phenomena will be raised in the rather small RBs. For the Chirchik-Akhangaran RB a change of the following parameters is expected: a) Reduction of glacier areas in mountains on 15-20% to 2030. Important factor, as glaciers are natural regulators of RF and influence on dynamics of seasonal flow; b) Reduction of RF's glacier part on 3-5 %, and increase of rain part of RF on 7-10 of %. Important factor, as repeatability of flood phenomena are connected to them; c) Increase of air-temperature all seasons of year. Insignificant factor, as they change on separate years and seasons in wider limits; d) Change of sowing's terms for agrarian cultures up to 10-15 days; etc. Insignificant factor, as these terms are strongly changeable for separate years. In this matter weather factors are more important in comparison with climatic; e) Some others, which require codification on an importance's degree for clearer representation of each problem and development of the appropriate measures for their decision.

INTRODUCTION

Last decades ecological problems occupy the conducting place on importance for the civilization's future of in a line of global problems of modernity. In turn, in a list of global ecological problems a problem of climate change (CC) is: a) large-scale on influence on the further development of mankind, b) complex on presence of interrelation with other ecological problems, c) complex owing to discrepancy of the knowledge about the mechanism of this process.

The man can not affect much on global geophysical processes forming a climate (heat exchange, atmospheric circulation etc) in such degree that is essential to change a climate in planetary scale. For example, from number of the basic geographical factors - climatic belts, altitude, longitude, distribution dry and water, topography, large oceanic stream, character of land surface (soil, vegetative, snow, ice covering, basically - their reflective ability), air chemical structure, which form a climate, only about last two factors it is possible to say that they can change owing to anthropogenic activity and affect on rather large territories' climate. Thus it is not necessary to consider a real opportunity to influence processes of clouds' formation and precipitation owing to their spatial limitation; their meaning for the global climate's formation is insignificant, as well as influences of woods' cutting down, artificial wood-planting, water redistribution (irrigation and drainage) etc. At the same time, industrial activity has affected change structure of atmospheric gases in a decisive degree and, accordingly, on conditions of solar beams' passage, on what the air temperature depends. Now it is impossible to deny that forecasting by experts a global warming (GW) takes place, but it is disputable that GW is caused by human activity only. In a context of the present analysis it is possible to approve that a question on decisive influence of GW on reduction of glaciers' area in the mountains of Central Asia (CA) is disputable also. This problem occupies one of conducting places in hierarchy of alarms for the future of water resources (WRs) in post-soviet CA, which includes 5 independent states (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan). Below problems of GW are considered from positions of importance or insignificance consequences of regional climate changes on regional WRs and factors connected to their quantity and use.

METHODS

In 1992 Intergovernmental Expert Group on Climate Change (IEGCC) proposed 6 scenarios (IS92a, IS92b, IS92c, IS92d, IS92e, IS92f) of global greenhouse gas (GG) emissions. According to above mentioned scenarios there are a number of global air temperature and atmospheric precipitation change scenarios, as these factors are main for WRs' dynamics.
Present analysis is carried out on the basis of the GG scenarios, which are proved for CA by experts of Central Asian Scientific Research Hydro-meteorological Institute (CASRHMI, Tashkent). Accounts are carried out by the experts for the GG scenarios integrated in pairs: IS92c and IS92d (minimal emissions), IS92a and IS92b (medium emissions), IS92e and IS92f (maximal emissions) are given. Experts used also model of river flow formation in the mountain areas, which allows to take into account the basic laws of flow formation and to estimate influences of climatic changes on river flow, snow cover, glaciers in scale of separate river basins etc. System of models includes models of the snow cover in mountains, model of the glacier part of the river flow and model of transformation of rain, thawed snow and glacier components to the river flow. These models take into account the basic regional features of the flow formation zone also. In particular, according accounts, in south mountain regions of CA expected warming doesn't exceed in summer 0.5°C, in winter 1°C. In high mountain depressions of Tang-Shan and Pamiro-Alai in summer a temperature reaches 1°C, in winter - 2°C. On average during the year warming values in given region don't exceed 1°C.

CLIMATE CHANGES AND REGIONAL WATER RESOURCES: THE IMPORTANT, MINOR AND DISPUTABLE FACTORS AND CONSEQUENCES

Water resources' volume and their seasonal dynamics

As well known, in CA there is water scarcity problem, the Aral Sea basin (ASB) concerns to regions feeling sharp water deficiency. Regions located in arid and semiarid regions are vulnerable to CC impact. Presumably, expected GW can strengthen this water deficit. The largest rivers of the ASB are Amudarya and Syrdarya. Accounts show that in the ASB multiyear WRs are formed in volume 116.5 km^3, from which in the Syrdarya RB - 37.2 km^3, Amudarya RB - 79.3 km^3.
Accounts under the regional climate change scenarios (CCSs) show that for the nearest 25 years essential change of WRs in the ASB will not take place, in the Amudarya RB their reduction is expected 2-4 %, Syrdarya RB – they are increased on 3-4 %. WRs' changes are less, than error of river flow's (RF) measurements (up to 5 %). Therefore regional RF's changes will not affect essentially on water distribution between the Central Asian States (CASs). Regional water organizations - Interstate Basin Water Organizations "Amudarya" and "Syrdarya", which carry out interstate

water allocation in the same RBs - have the right to change the established water volumes for each CAS within the limits of 10 % that strengthens insignificance of the given factor.

At the same time, in the relatively small RBs the sharper fluctuations of RF are expected. So, in Chirchik-Akhangaran RB (Tashkent oasis; watershed area - about 22000 km^2) the maximal changes of RF can make up to 6-8 % of increase (Chirchik river) and up to 6 % of reduction (Akhangaran river) during the vegetation period (April-September). If to take into account that the increase of rain and fast snow thawing are predicted, it is necessary to recognize this factor as very important, as the repeatability of flood phenomena are connected to them and will be raised in the rather small RBs. As a consequence, the basic problems of CC in small RBs will be concentrated at local level. It also will cause complexity of RF's regulation for separate period of vegetation. At the same time, it is necessary to consider critically above mentioned data in context of the contradiction's presence: why for adjacent RBs the different qualitative picture is observed - for the Chirchik RB RF is increased, for another (Akhangaran RB) – it decreases. This question requires logic substantiation.

Mountain glaciers and river flow

In CA mountain glaciers are the main source and an accumulator of fresh water's long-term reserves; they are also a natural regulator of RF. In CA mountain glaciers occupy the area about 18000 km^2. The basic part of glaciers is concentrated in Kyrgyzstan (about 8200 glaciers; total area - 8170 km^2; water equivalent - about 650 km^3) and Tajikistan (about 8500; 8500 km^2; 500 km^3). Other part of mountain glaciers (total area – about 1300 km^3) is located in Kazakhstan and Uzbekistan.

Last 6 decades the glacier areas' reduction is observed: more than 50 relatively small glaciers disappear and large ones are being broken. Analysis of data for 1965-1982 (the USSR Glaciers' Catalogue) shows that some glaciers have saved their stationary state or even increase (but linear size's increase was observed). For example, for the period 1955-1990 on northern periphery of Tang-Shan mountain system 57 glaciers have disappeared, and 131 new glaciers were formed at disintegration on 56 large glaciers, thus the total area of glaciers was reduced almost to 29.2 %. For majority of glaciers a typical reduction is observed: glaciers with area less than 1 km^3 disappear, and large glaciers are broken into small ones. According to the available data, more than 400 glaciers in CA tend to reduction of their area and volume. For instance, for 1995-2000 glaciers of CA were reduced annually approximately on 0.8-1.0 % of its volume and 06-0.8 % of area. For 1957-1980 glaciers within CA lost 115.5 km^3 that constitutes almost 20 % of ice reserves by 1957. By 2000 losses amounted for 14 % of 1957 reserves. By 2020-2025 glaciers will loose 10 % more from initial volume (1957). In particular, last estimation of the glaciers' volume for the Pskem river basin (RB) (Uzbekistan, Tashkent province) was executed by researches in 2001, and according to these estimations, glacier area in the Oigaing RB has made 38.8 km^3. By results of processing space pictures of 1980 the common glacier area in this RB has made 46.7 km^3. For last 20 years glacier area were reduced totally to 16.9 %, and to 2020 glaciers will be lost yet less by 17 % of initial volume, i.e. to 2020 the loss of weight will make 1/3 from volume of 1960. The factor is disturbing and requires deep study.

According to the available data, temperature increase by 0.50 C leads to glacier area's reduction: in the Sokh and Isfara RBs (Ferghana valley) - by 8 %, in the Oigaing RB (Tashkent oasis) - by 30 %. Mountain glaciers response to the air temperature increase differently, but it is very difficult to explain such large difference. In particular, attempts take place to explain it phenomena by different quantity of precipitation, which are predicted. But it seems that modern science can predict only short-term weather (not climate), instead precipitation's quantity. Probably, an introduction to the models the future precipitation quantity is one of disputable questions, especially, when they appear at accounts for mountain glaciers' dynamics. Regional CCSs show that air temperature will be raised in the winter periods more, than in summer. It is obvious that only positive (+) temperatures can influence on glaciers' thawing, and increase in limits of minus (-) temperatures should not be considered.

Climate Change and agriculture

Agrarian sector of the CASs uses about 90 % of all regional water resources is major branch of national economy. As negative consequences of CC for cultivated agrarian plants are called, accordingly to the regional CCSs, in particular, the following: a) increase of air-temperature all seasons of year; d) change of sowing's terms for agrarian cultures up to 10-15 days, and\or similar - acceleration of crop's maturing on 10-15 days etc. It is represented that named above and similar factors are insignificant in for considered case. So, in the first case (a) change of air-temperature on separate years and seasons in wider limits than it is predicted by the regional CCSs. In the second case (change of sowing's terms, acceleration of crop's maturing) the named factors' importance is represented also exaggerated, as these terms are strongly changeable for separate years. In this matter weather factors are more important in comparison with climatic. In dependence on weather conditions of spring terms of sowing of agrarian cultures are displaced for 1-2 months. For example, in 2007 (in conditions of the Tashkent, Syr-Darya, Dzhizak provinces of Uzbekistan) the terms of cotton's sowing were delayed from middle of March till second decade of May. Concerning to crop's maturing it is well-known: it depends on conditions of humidifying of soil more than from air temperature. Depending on intensity having watered or depths of groundwater the difference in terms of crop's maturing (cotton) can make about 1 month and more.

It seems that to the all predicted by CCMs consequences should consider critically and require codification on an importance's degree for clearer representation of each problem and development of the appropriate measures for their decision and with the purposes to avoid the vain expenditure and forces both means, and the efforts should be directed on prevention of those consequences, which are the valid instead of imaginary threat to human security.

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Impact of 20th Century Climate Change on Water Resources in Mountainous Regions of Switzerland

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Keywords:
Water balance, climate change, glacier mass balance, precipitation, heavy precipitation, runoff, temperature, snow, Alps, trends.

ABSTRACT

In the mountainous regions of the Swiss Alps climate change and its influence of water resources can be very clearly observed. Based on systematic observations that is available since mid 18th century, changes in temperature and in all water balance components are analysed and quantified. The mountainous topography demands specific methods for the analysis of some of the hydro-climatological parameters. Long time series show an important shrinkage of the glaciers, an increase of (winter) precipitation, an increase in evapotranspiration and at least for the northern part of Switzerland, stable runoff conditions. In the southern regions, runoff seems – at a high level – to diminish.

INTRODUCTION

The importance of mountains regarding their role as headwaters and sources for the water resources of lowlands is recognized for a time long since - especially in the scientific community. But it has been put to an increasing attention to politics since the debates at Rio Earth Summit in 1992 and even more during the International Year of Mountains 2002. With regard to hydrology, the symbolic term “water tower” has emerged (Liniger et al., 1998) and is now widely adopted, expressing the importance of mountains in providing freshwater for the adjacent areas downstream (Viviroli et al., 2007). Changing water resources in mountain areas will obviously have consequences on water resources in lowlands. This means that specific climate changes in the headwaters will affect the water availability of the lowland population which might experience different kind of climatic changes.

Man made induced climate change is not just a scenario for the future, but has been experienced since the beginning of industrialization which coincidences with the so called little ice age in mid 19th century. This paper analyses the changes in climate and especially in the hydrological cycle and in water resources for the last 150 years. In Switzerland and therefore in the Swiss alpine region climate and water resources have been fortunately observed for all that long time period.

Due to the former “Swiss Association of the Natural Sciences” (the today “Swiss Academy of Sciences”) that has been established 1823, first climate monitoring started at that time already. From 1863 systematic monitoring started: the Glaciological Commission was in charge for Swiss glaciers, the Meteorological Commission for the climate observation and the Hydrological Commission for the observation of lakes and rivers. Within few years National State Agencies have been established which have been charged to assure the long term and systematic observation of the climate and the hydrological cycle: The Swiss Meteorological Institute and the Swiss National Hydrological Survey, which is today a department of the Federal Office for the Environment. Glaciers are still observed by the Swiss Academy of Sciences.

TEMPERATURE AND PRECIPITATION

Temperature and precipitation are the climatic factors that influence most the hydrological cycle. Both are available for a very long time. For Switzerland 12 stations are available that cover the time period starting 1864. Seven stations are located in the lower areas below 1000 m a.s.l., four between 1000 and 2000 m and the highest at 2490 m. As the exact location was displaced and the instruments have changed for several times, it was necessary to homogenize all but one time series (Begert et al., 2005). Most of the yearly and seasonal temperature series show a significant positive trend. The slopes of the yearly series range from 0.9 ˚C/100 years to 1.2 ˚C/100 years on the northern side of the Alps and the central valley whereas on the southern side of the alpine main crest smaller slopes of 0.6 ˚C/100 years are observed. Looking at seasonal values, largest increases are found in autumn for stations with higher elevations (0.8 to 1.3 ˚C/100 years) and in winter for stations at elevations < 1000 m a.s.l. ranging from 0.9 ˚C/100 years to 1.6 ˚C/100 years (Begert et al., 2005). Compared to the temperature trend of global mean with 0.42 ˚C/100 years and the northern hemisphere land surface with 0.63 ˚C/100 years (IPCC, 2007) the over all trend in the Swiss Alps is about 1.4 to 2.4 respectively 1.0 to 1.6 times higher. Clearly, the times series do not show a continuous increase in temperature but two distinct jumps at the beginning and close to the end of the 20th century. (Rebetez and Reinhard, 2007) identified as a mean value in Switzerland for the period 1975-2004 a linear trend of 5.71 ˚C/100 years, which is more than 2 times higher than for the northern hemisphere.

For precipitation significant trends are observed for yearly values only at 4 stations in the lower areas: the slopes of the trends range from +7 to +10% per 100 years (Begert et al., 2005). As for the seasonal values only for winter season significant precipitation trends are found at all but the southern stations. The strongest trends are observed in the western part of Switzerland with +35 to +37% per 100 years. For the other stations the values amount to +16 to +25% per 100 years. However, looking at progressive analysis of the yearly and of the winter series it becomes clear that the trends are strongly influenced by the time period with higher precipitation amounts starting between 1940 and 1950, and even more pronounced starting around 1970 (Bader and Bantle, 2004). These findings are comparable with results of other studies that, however, analysed different time periods and different data sets (Widmann and Schär, 1997; Frei et al.; 2000; Schmidli et al., 2002; Schmidli and Frei, 2005).

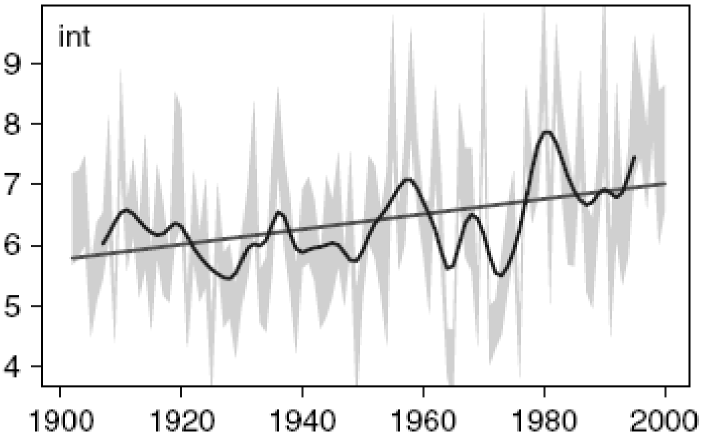

Figure 1. Time series of precipitation intensity (mean wet-day precipitation in mm/d) from 38 stations of northern Switzerland in winter. The blue curve demarcates the lower and upper quantile of the station values. The bold line depicts the low-pass filtered (11-point binomial filter) median of all station values. Trends (straight red line) are estimated from the time series of medians in the station pool. Figure from (Schmidli and Frei, 2005).

For the assessment of changes in natural hazard, risks trends in heavy precipitation are important. In a comprehensive study (Schmidli and Frei, 2005) analysed 100-year (1901-2000) time series of 104 rain gauges in Switzerland. A clear trend signal has been found for winter and autumn for all statistics related to precipitation strength and occurrence. The centennial increase is between 10 and 30% for the high quantiles and the seasonal 1 to 10 day precipitation. The winter trend signal is strongest in northern and western Switzerland (figure 1). However, these trends are no longer valid if we look further back into the past. (Hegg and Vogt, 2005) analysed yearly maximum daily precipitations measured at 18 stations in Switzerland from 1864 to 2002. They found that in the time period between 1890 and 1970 maximum yearly 24h-precipitation were mostly lower than before or after this time period. And consequently they found only for one station (in the southern part) a positive trend for the whole period.

Snow and Ice

Seasonal snow cover is heavily influencing the runoff regimes in mountainous regions. During winter season the snow pack is growing in many prealpine and in most alpine regions whereas it melts in spring and summer season up to altitudes of about 3000 to 3500 m a.s.l. depending on exposition. Time series of 190 observing stations between 275 and 2540 m a.s.l. have been analysed for the time period 1931 – 1999 (Laternser and Schneebeli, 2003). Even if a considerable interannual and spatial variability of snow parameters is observed, mean snow depth, duration of continuous snow cover and the number of snowfall days show very similar trends. No uniform trend is discernible over the whole period: a gradual increase until the early 1980s is followed by a statistically significant decrease towards the end of the 20th century. The latter finding is confirmed by the analysis of 27 long term water equivalent time series: annual maximum water equivalent values are decreasing for most stations since the 1980s. Generally, relative trends are negligible for altitudes above 1300 m a.s.l., whereas large negative trends of up to -2.5%/yr are found for lower stations (500 m a.s.l.). Model analysis showed that in general the shift in temperature explains most of the trends (Scherrer and Appenzeller, 2004).

In Alpine glaciers water is stored over relatively long time periods. During the so called Little Ice Age the last maximum glacier stage was reached around 1850. In Switzerland about 110 billion m^3 ice (see Table 1) was store, that covered at that time about 1800 km^2 (4.3%) of the Swiss territory. Between 1850 and 2000 about 40% of the glaciers surface and about 50% of the ice volume disappeared due to the temperature rise (Maisch et al., 2004). These figures are comparable to the changes in ice in the entire European Alps where initially 200 billion m^3 ice under a surface of about 4475 km^2 were stored. By 2000, in the European Alps shrinkage was more pronounced, due to the lower mean altitude compared to the Swiss Alps: surface diminished by 50%, volume losses amount to 62% (Zemp et al., 2006). Due to the extraordinary warm summer 2004 in middle Europe about another 10% of the ice volume has disappeared (Frauenfelder et al., 2005; Huss et al., 2007).

year	**European Alps**		**Switzerland**	
	ice (10^9 m^3)	**water (10^9 m^3)**	**ice (10^9 m^3)**	**water (10^9 m^3)**
1850	200	182	110	100
1973	100	91	75	68
2000	75	68	55	50
2006	67	61	49	45

Table 1: Water storage in Europen Alpine Glaciers from Little Ice Age until present (Maisch et al., 2004; Zemp et al., 2006; Frauenfelder et al., 2005; Huss et al., 2007).

Water balance and runoff

Changing climate with increasing temperature and changes in the precipitation regimes have a distinct influence on the runoff regimes and on water balance. (Birsan et al., 2005) analyzed daily streamflow records beginning in 1931 of 13 near natural watersheds in Switzerland. They identified a change in runoff regimes toward higher runoff in winter and lower runoff in the other seasons. For the shorter time period 1971-2000 the trends in 49 time series was positive for yearly values and all seasons, but still most pronounced in winter, due mostly to a increase of the high runoff quantiles or even in the maximum runoff. This last finding is comparable to the above mentioned increase in precipitation in many parts of Switzerland during winter season. A statistical analysis clearly indicates a correlation of positive runoff trends to mean basin elevation and glacier and rock coverage. This relationship suggest that – besides precipitation changes - changes in snow and ice distribution due to temperature change influences most the shift of regime of individual watersheds. Obviously, regime types (Aschwanden and Weingartner, 1985) changes from ice-and snow influenced regimes to more snowmelt and rainfall influenced regime types.

Yearly water balance time series since 1901 based on measured data have been established and analysed by (Schädler, 1985), (Schädler and Bigler, 1992) and (Schädler and Weingartner, 2002). Recently, special importance has been put onto the fact that quantification of areal precipitation in mountainous environment is still a very difficult task. Aiming at a high spatial resolution a specific methodology has been developed which is based on a comprehensive view of the water balance in different spatial and time scales (Weingartner, Viviroli and Schädler, 2007).

For Switzerland the water balance has been established for the four most important river basins (table 2): Rhine (27’970 km^2; northern part), Rhone (5’220 km^2; western inner Alpine part), Ticino (1’515 km^2; southern part) and Inn (1’944 km^2; eastern inner Alpine part of Switzerland) and also for the entire territory of Switzerland (41’287 km^2).

	Precipitation P (mm/a)					**Natural Runoff R (mm/a)**					**Evapotranspiration E (mm/a)**				
	Switz.	Rhine	Rhone	Ticino	Inn	Switz.	Rhine	Rhone	Ticino	Inn	Switz.	Rhine	Rhone	Ticino	Inn
Mean	1429	1404	1432	1829	1215	992	949	1090	1421	928	448	461	386	411	302
Standard deviation	201	205	234	342	180	153	165	135	309	130	71	78	90	128	92
Maximum	1844	1832	1931	2942	1650	1312	1286	1390	2336	1284	625	658	708	754	549
Minimum	859	849	775	1048	754	629	527	759	779	611	247	251	121	125	96
Trend	1.20	1.18	2.03	-0.22	-0.11	0.07	0.07	0.83	-2.18	-0.42	1.05	1.07	0.87	1.92	0.15

	Storage Change (Glaciers) (mm/a)				
	Switz.	Rhine	Rhone	Ticino	Inn
Mean	-11	-6	-44	-3	-15

Table 2: Water balance elements for the time period 1901 – 2000 for 4 river basins of Switzerland and for Swiss territory.

Depending on climate region and on topography, precipitation amount varies considerably: highest values and highest variability are observed in the south of the Alps, in Ticino basin. Lowest values are measured in the inner Alpine valley of the Inn, which is protected from winds of all directions. Trends for precipitation are inhomogeneous for seasons and for regions and therefore no significant trends for these basins over the entire time period are detected, even if it seems obvious from figure 2.

Evapotranspiration depends basically in almost all regions on temperature. It amounts - due to abundant precipitation - most of the time to almost the same values as potential evapotranspiration. Indeed, a significant positive trend in all but the Inn basin can be observed.

As a result, the distribution of runoff values is similar to the finding in precipitation. For the Rhine basin runoff values remain constant as the amount of the rising evapotranspiration is compensated by the almost same amount of the rising precipitation. For Rhone, precipitations seem to increase more, resulting, together with a contribution from melting glaciers, in a higher runoff. Whereas for Ticino and also less pronounced for Inn, runoff diminish due to less precipitation.

The contribution of ice melting to the mean runoff is often overestimated. Even if during the 20th century 53 billion m^3 of glacier ice disappeared in Switzerland, the contribution to the mean runoff amounts only to about 1%. However, for individual small watersheds close to the glaciers, the contribution of melt water from glaciers is important. Changes here result in the changes of runoff regimes that are already discussed before.

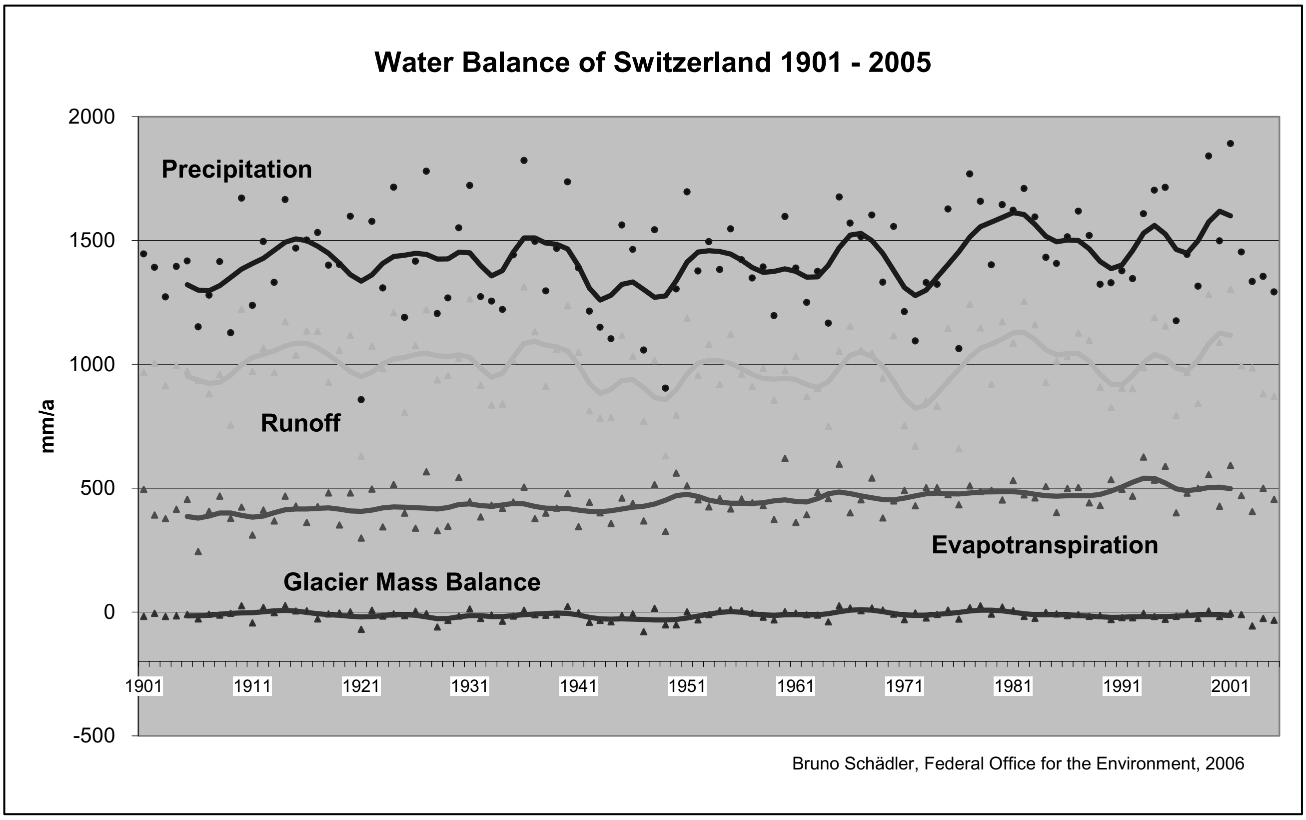

Figure 2: Water balance of Switzerland. Points are values for the hydrological years, the lines are 9-years low-pass Gaussian filtered values.

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Water resources change perspectives in Central Asia as consequence of global warming and glaciers degradation

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ABSTRACT

The results of glacier monitoring leave no ground for doubting the degrading stage of the Earth glaciation dynamics in the second half of the XX c. The rate of glaciation area reduction in Central Asia, remained one of the most intensive in the world. Starting from the end of 80s – beginning of 90s, the rates of glacier retreat in many parts of the world increased to a great extent.

Predominating opinion about the inevitability of glaciers disappearance in Central Asia mountains cannot be accepted as an axiom. Based on our analysis, which takes into account current global warming trends, the glacier area of Balkhash basin may shrink by about one-third but will not disappear completely.

Despite the reduction of glaciers, annual runoff volumes and runoff distribution within a year remained unchanged during the last decades. During the same period, norms of atmospheric precipitation and maximum snow reserves in the zone of runoff formation, remained stable. All these suggest the existence of a certain compensation mechanism. Such mechanism can be an increased (with climate warming) participation of melting waters of underground ice (buried glaciers, rock glaciers, permafrost) in the river runoff. Taking also into the consideration the fact that reserves of underground ice in high mountains of Central Asia and Kazakhstan are equivalent to the present-day glacier resources and in the Chinese mountains they are two times greater, and also considering that the rates of melting underground ice are much lower than those of the open glaciers, we believe that even if the present-day trends in climate warming are preserved, the above mechanism may work for hundreds of years. Hence it can be predicted that the ongoing degradation of glaciers will not cause considerable reduction in the runoff and regional water resources at least up to next decades.

INTRODUCTION

During the last 15-20 years a lot of scientific papers were published whose authors showed increasing concern about considerable reduction of water resources in arid regions caused by ongoing global warming. One of the arguments justifying the above predictions is unarguable fact of ongoing intensive degradation of mountain glaciation: only in the period from 1956 to 1990 glacial resources in mountains of Kazakhstan and neighboring countries decreased by more than one third and is still decreasing at a rate of about 1% per year (UNEP, 2005, Severskiy 2006). If these tendencies are preserved in future, then by glaciologists' estimations glaciers in Kazakhstan's mountains will practically disappear by the end of this century (Vilesov, Uvarov 2001). It may really make it is necessary to review all system of water supply in the countries of the region as on going out form mountains glacier waters make up to 25% of annual runoff of the main rivers of the region and 50% of the runoff in the vegetation period.

In the conditions of Central Asia vary important to estimate how current degradation of glaciation will influence river runoff. It is one the first priority problems if one takes into account that according to prognosis estimations as a result of global warming water resources of the main rivers of Central Asia and Kazakhstan, including the Amudarya, Syrdarya, Ishim and Tobol, may decrease by 20-40% already in the next few decades (Chub , 2001, Golubtzov et al., 1996, Skotzelias et al., 1997).

METHODS AND RESULTS

Contemporary and Predict Changes of snow-ice and renewable water resources

In the conditions of Central Asia melt snow and ice water contribute decisively to the formation of renewable water resources, so, evaluation of possible changes in water resources in the foreseeable future implies reliable prediction of the changes in snow- ice resources. As to the recent fluctuations of snow cover in the region under examination, the situation is more or less clear: according to analysis in Northern Tien Shan, for the last decades the average maximum snow-water equivalent (the main component of snow resources) has not changed (Pimankina ,1998; Schröder, Severskiy, 2004). Similar results were found for Western Tien Shan and Gissar-Alai by professor G.E. Glazirin(unpublished) and B.F. Tsarev(Artemjeva, Tsarev, 2003). The norms of rivers' runoff have been steady as well (Chub, 2001, Schröder, Severskiy , 2004).

The situation in evaluation of the dynamics of ice resources is more complicated. At the same time, existing findings (Cherkasov, 2002, Dikhich, 2001, Dikhih et al., 2001, Shchetinnikov, 1998., Shchetinnikov, Likhacheva, 1994., Vilesov, Uvarov, 2001) allow to conclude, that glacial systems of Central Asia mountains develop in the same direction and have similar rates of modern changes. So, for the last decades the area of glaciers in different regions of Tien Shan, Gissaro-Alai, Pamirs and Dzhunghar Alatau has decreased at the average rate 0.8% per year (Cherkasov, 2002, Dikhich, 2001, Dyurgerov,1995, Kotliakov, Severskiy, 2007, Shchetinnikov,1998., Shchetinnikov, Likhacheva, 1994). Taking into account those results, it is possible to suggest, that contemporary and prognostic changes in ice resources of Central Asian mountains can be studied on the example of a single representative area ensured with reliable information on glacier dynamics. In Central Asia such area is the basin of the Ili River– the main water stream in the Balkhash lake basin. Transboundary basin of the Ili River includes glacial mountains of Northern Tien Shan and Dzhunghar Alatau in Kazakhstan, and also East Tien Shan and Dzhunghar Alatau in the territory of China. The biggest glaciers are concentrated on the Chinese part of the basin, however, Zailiyskiy-Kungei and Dzhunghar glacial systems located within the limits of the Ili River basin in the territory of Kazakhstan, are rather typical for the glaciation of entire region. Just those glacial systems have a most reliable information necessary for the solution of our task.

The dimensions and temps of the glaciers degradation have been determined on the base of comparison of the detailed glaciers Catalogues (Glacier Inventories), composed by the aero-photograph materials. Therefore we have an opportunity to compare parameters of glaciers of the Ili-Balkhash basin: Dzhunghar glacier system (1956 and 1972), Zailiyskiy-Kungei glacier system (1956, 1975, 1990) and glacier system of the northern slope of Zailiyskiy Alatau (1955, 1975, 1979 , 1990 and 1999). One should pay attention to the fact that the rate of reduction of degradation area (R%/year) increased during the period under consideration (Table 1, Fig. 1).

Table 1. Changes of the total area of the open glacier parts in Zailiyskiy-Kungei glacier system during the 1956-1999 period.

Region	Glaciation area, km^2					
	1955/56		1975	1979	1990	1999
	Under Glacier inventory	Corrected				
1	135,7	143,8	109,9	(103.5)	(92.5)-	84.1
2	137,4	145,6	138,4	(131.9)	(121.4)-	114.9
3	271,2	287,3	240,4	228.2	204.7	188.2
4	276,9	293,5	259,9	243.8	222,6	(204.6)

Region	Annual rate of glaciation area reduction, %					
	1955/56-1975	1975-1979	1979-1990	1990-1999	1955/56-1990	1955/56-1999
1	1,241	1.456	0.966	1.009-	1.049-	0.965
2	0,260	1.174	0.723	0.595	0.489-	0.490
3	0,816	1.269	0.936	0.896	0.821	0.784
4	0,602	1.549	0.790	0.928	0,603	0.723

Note: 1-Southern slope of Kungei Ala-Too; 2- the Chon-Kemin river basin;
3- Northern slope of Zailiyskiy Alatau; 4- the Shelek river basin.

If in the period from 1955 to 1975 the rate of degradation was 0.816% per year, in the period from 1975 to 1979 it already exceeded 1.27% per year. As it is seen from Figure 1 a sharp jump of the rate of glaciation degradation happened in middle of 1970s. The same character of glaciation dynamics was observed for the Yazgulem river in Western Pamirs (Glazirin, Kodoma , 2003).

Table 1 presents the data on degradation of the glaciation area of the most well studied Zailiyskiy-Kungei glacier system. One should keep in mind that the column "corrected" contains glaciation areas corrected by multiplying on coefficient 1.06. This coefficient was obtained as a ratio of initial values of (1955/56) of total glacier area determined for the northern slope of Zailiyskiy Alatau by the maps of scale 1:25 000 and 1:100 000. The table shows territorial and time non-uniformity of the rates of glaciation degradation in the studied region. In the period from 1956 to 1975 maximal rate of Glaciation reduction 1.241% per year was observed on the southern slope of the ridge Kungei Ala-Too and the minimal rate (0.26% per year) – in the Chon-Kemin basin. The rate of reduction of glacier area in the Shelek river basin(0.602% per year) was also much smaller than that for Zailiyskiy-Kungei glacier system. The reasons for high rate of degradation of southern slope of Kungei Alatau are quite obvious but slower rates of degradation of the Shelek and Chon-Kemin river basins are not clearly understandable. The main reason for relatively slow reduction of glaciation area in the latter basins is, from our point of view, their orography and considerable increase of the summer fraction of precipitations in the annual sum in the direction from west to east (Severskiy et al,2006).Often summer precipitations the overwhelming part of which falls out in solid form in glarier region promote glacier "conservation" and reduce intensity of their melting. Similar conditions probably exist in the Chon-Kemin river basin open for intrusion of moisture-carrying air masses from west and northwest(Severskiy et al,2006) The average annual rates of decrease of

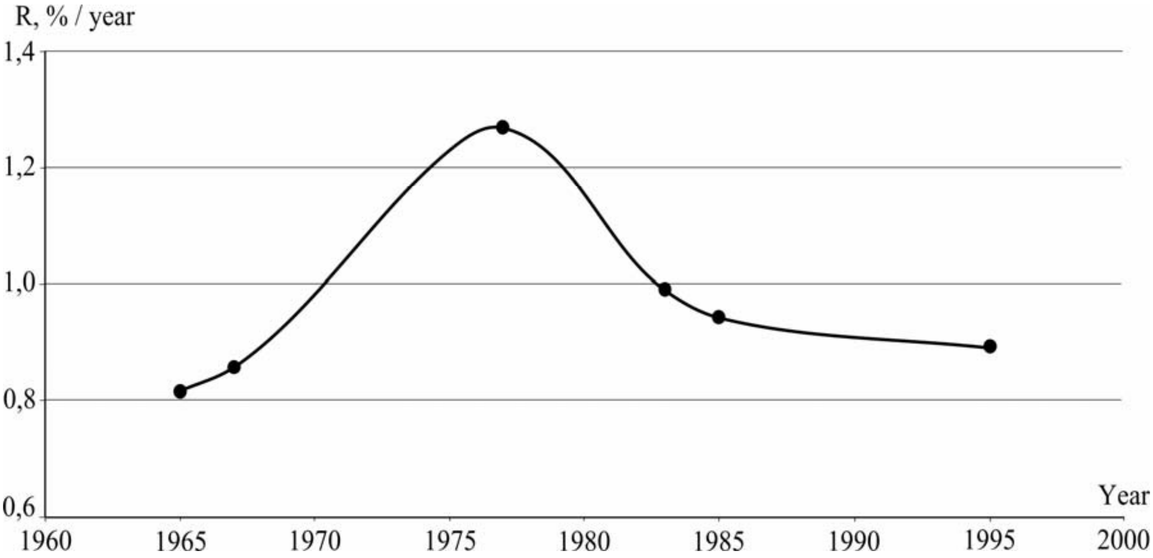

Figure 1– Changes of the rate of reduction of degradation area on the northern slope of Zailiyskiy Alatau

glaciation areas may be different even for neighboring basins. This conclusion is well illustrated by table 2 which presents characteristics of glacier degradation in Dzhunghar glacier system.

It is interesting to consider territorial distribution of glaciation area: average rate of the glaciation area shrinking (for the period from 1956 to 1972) was 1.185% where maximal values (1.342% and 1.239%, respectively) refer to northern and southern slopes of the ridge Dzhunghar Alatau. Minimal values of degradation (0.662% per year) refer to the eastern part of the mountain system – the Tentek and Yrgaity river basins. These results show the influence of orography and the above-mentioned effect of increase of the fraction of summer precipitations in the annual amount from west to east. No less clearly territorial –temporal differences are appeared in change of the ice volume reduction rates of glacier systems (Severskiy et al,2006).

Table 2. Variation of total glacier area (pure ice) of Dzhunghar glacier system for the period from 1956 to 1990.

Region, river basin	Glaciation area, km^2			Annual rate of glaciation reduction for the period , %		
	1956	1972	1990	1956-1972	1972-1990	1956-1990
Southern slope of Dzhunghar Alatau ridge	242,1	194.1	153.0	1.239	1.175	1.082
Karatal river basin	214,6	176.0	149,1	1.123	0.846	0.895
Bien, Aksu, Lepsy rivers basins	312,3	245.3	218,6	1.342	0.603	0.884
Tentek and Yrgaity rivers basins	93,7	83.8	70,9	0.662	0.859	0.715
Dzhunghar glacier system as whole	862,7	699.2	591.6	1.185	0.854	0.924

Note: In 1990 glaciers of area less than 0.1 km2 were taken into account. The area of glaciation in 1956 was determined by the Glacier Inventory taking into account coefficient K = 1.06 obtained as the ratio of glaciation area determined by 1:100, 000 maps to that determined by 1:25,000 maps. The Southern Dzhungharia glaciation area obtained by the data of A.L. Kokarev and I.N. Shesterova using glacier boundaries outlined by P.A. Cherkasov on 1:25,000 maps.

Thus the average rate in the decrease of glacier area on the northern slope of the Zailiyskiy Alatau was 0.82% per year for the period from 1955 till 1990 and the corresponding figure for the decrease in the net glacier volume was about 1.0% per year(Severskiy et al, 2006). If we take the rates of glaciers' areas and volumes decreasing, calculated on the base of complex percentages equations, as the basis, than the Zailiyskiy Alatau glaciation degradation can be expressed by values represented in table 3.

Table 3. Prognosis of glaciers volume of the Ili river basin for the nearest decades

Region	Volume of ice in glaciers, km^3					
	2000	2010	2020	2030	2040	2050
Kazakhstan's part of the Ili River Basin	35.04	32.91	30.08	27.50	25.14	22.99
Chinas part of the Ili River Basin	90.41	87.32	79.83	72.98	66.72	60.99
Total	125.45	120.23	109.91	100.48	91.86	82.98

Thus, by the middle of this century glaciation of the mountains of Central Asia will reduce only by one third and will not disappear by the end of the century as it was supposed previously (Cherkasov, 2002, Dikhich, 2001, Dikhih et al.,2001, Vilesov, Uvarov, 2001).

Water resources change perspective

Comparison of the results of the repeated photogrammetrical surveying of the Tuyuksu's group of glaciers allows to make some conclusions concerning water resources change perspectives of the region(Severskiy et al,2006).The fact that in spite of the considerable degradation of glaciation, together the stability of the mean perennial sums of atmospheric precipitation and maximal snow-water equivalent, the runoff norms during last decades did not practically change, gives the reason to suppose the presence of a certain compensating mechanism. Such mechanism can be all the more(as of the climate warming) participation in runoff formation of the thawing waters of underground ices, including accumulated ones, in perennial permafrost.

At least, two facts testify a reality of such mechanism. According to the results of observations, the depth of seasonal thawing of ground in the boreholes at the Zhusalykezen Pass has increased not less than by 1.1 m for the period from 1973 to 1996 (Gorbunov et al.,1997). Thus, for the specified period melt waters from more than one meter thick layer of recently frozen ground could contribute into the formation of run-off. Application of isotope methods to the study of genesis of water resources also confirm a reality of the mentioned compensatory mechanism. According to the results of the study, the lake-dam complexes of alpine areas of Kyrgyzstan (Top-Karagai, Tuyuk-Tor, Kashka-Suu streams) by 40-50 %, and in a number of cases are completely formed for the account of buried moraine ice (Tuzova, 2002).

Total losses of ice volume of the buried part of the Tuyuksu group of glaciers during 40 years have been 0.01949 km3 which is equivalent to 20.4 % of the total losses of ice of the open part of the Tuyuksu group of glaciers. In other words the volume of water formed out of thawing of the buried part of the glaciers was 20 % of the total runoff formed at the expense of thawing of the age-old reserves of the open part of the before-indicated group of glaciers. This is very considerable value which yet did not taken in consideration in water balance calculation. It can be surely consider that namely thawing waters of the buried glaciers and rock glaciers compensate the greater part of the runoff losses connected with decrease of the ablation area of the open part of the glaciers providing runoff norms stability at the conditions of glaciation degradation. Because the resources of underground ices are comparable with ice resources of the modern terrestrial glaciation (Gorbunov., Severskiy,2001, Gorbunov et al.,1997, Marchenko, 2003) under conditions of precipitation norms stability and maximal snow-water equivalent it is possible to consider that even in the case of continuation of the intensive degradation of glaciation the runoff characteristics including indices of inner-year distribution during nearest decades will not considerably change. Sureness in similar dynamics of water resources in visible future gives also the fact that more than 70 % of the total glacier runoff is forming at the expense of thawing of the seasonal snow cover on the surface of glaciers and only about 30 % of it is forming at the expense of thawing of the age-old resources of glaciers ice (Vilesov, Uvarov, 2001). Results of estimation of the total volume of thawed waters set free during thawing of perennial frozen grounds (perennial permafrost) during period indicated are given at the shows that total volume of thawing waters incoming into discharge out of thawness of perennially frozen grounds over isohypse of 3200 m during period indicated was not more than 1.5 km3, i.e. 65.2 thousands m3 per year. This is only about 6.5 % from the volume of annual discharge formed at the expense of the thawing of secular resources of ice of the open part of the glacier Tuyuksu on the average during period of 1958-1998. Therefore as the basic compensation runoff, in spite of expectations, is forming not at the expense of thawing waters of perennial permafrost but at the expense of thawing of the buried glaciers and rock-glaciers.

It is also necessary to have in account that participation mechanism of thawing waters of glaciers and thawed perennially frozen grounds does not remain constant from year to year and in greater degree depends from thermal regime peculiarities of grounds and conditions of snowiness.

During warm years when the temperature of ground depths are relatively high and seasonal frost penetration is not high all the thawing waters participate in discharge formation and water balance of the territory of glacial-nival belt is near zero. During the years when temperature of frozen grounds is lowered, part of thawed water, penetrating into rock depth, again freezes and stays in such a state till the end of ablation period, creating transit resources of water. During such years discordance of water balance of the territory of the glacial-nival belt will be negative. The same "preserved" resources of water can go into runoff during the further years, being the cause of difficultly to explain, for the first look, positive discordance of water balance. Because multi-snowy and with little snow and also warm and cold years have a tendency to group into periods of 2-4 years in succession, the duration of period of negative or positive discordance of water balance is in average 3 years.

CONCLUSIONS

Predominating opinion about the inevitability of glaciers disappearance in Tien Shan mountains and in neighbor countries of Central Asia cannot be accepted as an axiom. Taking into account stability in the rate of precipitation and especially in the rate of snow resources, one can suppose that glaciers in this region will not disappear during this century. The norms of rivers' runoff have not changed either.

The fact that in spite of considerable reduction in glacier resources the flow rates of the main rivers practically have not changed during the last decades is an evidence of some compensating mechanism. Such mechanism can infer water inflow from underground melted ices, including accumulated in the perennial permafrost. Until now this circumstance has dropped out of the sight of scientists. Taking into account extreme importance of probable changes in water resources as a reaction to climate changes, this aspect of the problem deserves special attention.

The forecasted for the nearest decades the significant diminution of the water resources, connected with the anthropogenic caused warming of climate are scarcely probable. Though this optimistic conclusion gives us a chance to predict the development of the situation in the near future, it does not make the problem less acute: water shortage in the region is one of the limiting factors of its sustainable development. At the same time transboundary nature of regional water resources is one of the main premises for the development of international processes in Central Asia. Analysis of the situation in the region leaves no doubt that there is no alternative to the search for the ways of coordinated inter-state management of regional water resources.

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Hydrology for food security and poverty alleviation in northeastern region of India

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ABSTRACT

The northeastern region of India, with an area of 255 090 km^2, is predominantly hilly. Even though the region is endowed with rich water resources, it has remained economically backward due to gross mismanagement of these resources. The prevalence of shifting cultivation, the land ownership pattern, small and fragmented and holding, free range grazing, low accessibility, lack of proper infrastructure and marketing facilities are the major socio-economic constraints hindering judicious management of water resources. Shifting cultivation, involving deforestation, alone results in an annual loss of 88.3 million tones of soil and 148 thousand tones of nutrients through erosion. With an increase in population from 10.5 million in 1951 to 38.5 million in 2001, there is tremendous pressure on land, water and forests. The heavy annual rainfall of 250 cm has caused unabated soil erosion in the hills, and silting of riverbeds and floods in the plains. About 601 and 1.5 million tones of soil and nutrients, respectively, are displaced every year from the region. Among the natural factors, heavy rainfall and among anthropogenic factors, mismanagement of rain water, aggravate the problems of land degradation, soil erosion, low crop productivity and poverty. The region had a food grains deficit of about 0.5 million tones in 1971, which increased to 2.1 million tones in 2001. A multidisciplinary-long term study on various land use systems was undertaken to evaluate their performance with regard to runoff, soil and nutrient loss, *in-situ* rainwater infiltration, crop productivity and its impact on ecology and socio-economic conditions of the people of the region as against shifting cultivation. The results showed that only 0.16 to 8.03 tones of soil is lost and more than 90% of rainwater was retained *in-situ* in new land use systems as against 45.0 tones of soil lost and 66.3% rainwater in shifting cultivation. The crop productivity was 3 to 4 times higher in new land use systems than shifting cultivation. Due to more infiltration of rainwater in the oil, the runoff has considerably reduced, resulting in low flows to river channel and reduced incidence of floods.

INTRODUCTION

Water and agriculture are intimately linked as fundamental condition for food security and human development. Agriculture is by far the largest user of worlds' fresh water resources (FAO, 2002). Anthropogenic activities, especially those related to agriculture often result in increased nitrate in the aquatic eco-system. It is typical of non-point source pollution by agriculture and residential activities (Van Herpe & Troch, 2000). The northeastern region of India is endowed with rich natural water resources but their indiscriminate use and mismanagement have caused resource degradation to the extent that quality and quantity of available water has been affected (Sharma, 1998, 2003). The fast growing population has pressurized the food production base and to satisfy their needs, the people have misused the water resources. The region has a foodgrains deficit of about 2.0 million tones (Sharma, 1999). Besides other factors, mismanagement of water resources has been the major cause of low productivity. There is an annual loss of 601 million tonnes of soil with runoff, out of which shifting cultivation alone is responsible for 88.3 million tonnes (Sharma & Prasad, 1995). The region receives about 510 km^3 of rain water, annually, at an annual average of 2450 mm. There are two major rivers viz. Brahmaputra and Barak, draining an area of 194.4 and 78.1 thousand km^2 with an annual runoff of 537.2 and 59.8 km^3 of water, respectively. The main problem of facing the harmonious development and management of water resources in north-eastern region of India, apart from socio-economic constraints, is the paucity of reliable data and lack of human and institutional capacity necessary for confronting the complex interactions of the hydrological cycle with the social needs and the ecology. Judicious management of water resources will not only reduce the heavy loss of soil and nutrients but also reduce the flood events in the region due to reduced runoff. Water is an essence of life and its conservation, development and planned utilization is of prime concern for resource conservation and food security (Sharma, 1999). A multi-disciplinary study was, therefore, undertaken to evolve resource friendly, sustainable and ecologically sound land use systems to replace shifting cultivation for integrated management of water resources.

STUDY SITE AND METHODOLOGY

The study pertain to the northeastern region of India, comprising seven states (Fig. 1). Shifting cultivation is practised in 3869 km^2 area, annually in the region; however the total affected area is 14660 km^2. It has resulted in huge soil erosion in the hills and silting of river beds and floods in the plains. The land in the hills generally belongs to either the village chief or the community and so the farmers do not take much interest in the land and water resources management. This has put the whole ecology of the region in peril. To evolve eco-friendly, viable and sustainable land use systems, a multi-disciplinary, long term study was started in 1983, with different land use systems, to monitor their comparative efficacy with regard to *in-situ* retention of rain water, water yield as runoff, surface and sub-surface flows and loss of soil from different watersheds. The land use systems are based on agriculture, horticulture, silviculture and pasture grasses and fodders (Table 1). The slopes of the watersheds vary from 32 to 53%.. Different soil conservation measures used are bench terracing, half-moon terraces, trenches, contour bunds and

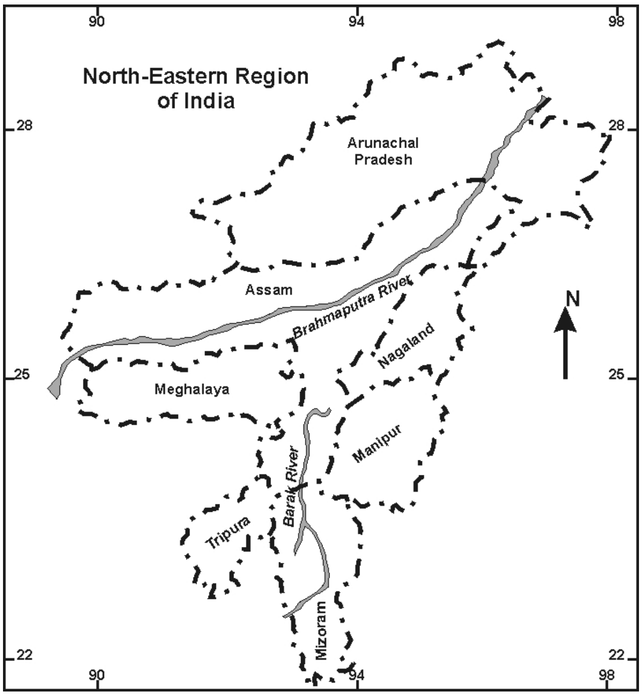

Fig. 1. Northeastern region of India.

grassed water-ways. The major thrust was to monitor hydrological behaviour of different land use systems, soil conservation measures to be adopted, rain water harvesting to reduce runoff and its judicious use for irrigation and fisheries.

DISCUSSION

Shifting cultivation and its impact

Different factors responsible for integrated water resources management in the northeastern region of India may broadly be classified as environmental and biotic, while under edapho-climatic conditions; topography, water bodies and climate have their role to play; under biotic factors, socio-economic conditions and land use pattern determine the fate of available water resources. The pattern, intensity and quantum of annual precipitation being unique in the region, proper management of rain water can be helpful in managing water resources to a large extent. The rural economy of the region is mainly dependent on shifting cultivation, practiced in 3869 km-^{2} and affecting 14660 km^{-2} area. In the past, when the land was in abundance and population sparse, the rotational cycle of shifting used to be 25 to 30 years and the land used to get enough time for rejuvenation. The soil fertility was maintained with *in-situ* burning of vegetation and the production was enough to feed the limited population. However, with increase in population from 10.5 in 1971 to 39.2 million in 2001, the rotational cycle has come down to 2 to 10 years and the land does not get enough time for rejuvenation. The soil fertility has declined as there is limited material to burn and add to the soil. Shifting cultivation is not only a set of agricultural practices but implies the whole nexus of people's religious belief, attitude, self image and tribal identity. This was mainly because of lack of opening up of more avenues or alternate land use systems for food security and livelihood. The land tenure system in northeastern region is unique. The land belongs either to (i) village chief, (ii) community or (iii) indivisuals. In the first two categories, the farmers have usufructuary rights over land and so they have least interest in its development and as such do not make judicious use of available water resources. The prevalence of free range grazing by animals during winter season (December to February) by community order, discourages the cultivators to go for winter crops. Fast urbanization and change in life style of the people has also affected the water resources management. Unabated deforestation in the region due to shifting cultivation as well as for making easy money, has depleted the resource base, resulting in land and water bodies degradation.

Resource degradation

Continuous deforestation in the region has resulted in soil erosion, loss of soil fertility, and land and environmental degradation, rendering the hydrological system in a fragile state. Deforestation and denudation of basins have caused water scarcity because the natural water cycle has been upset. The runoff water goes untapped from the denuded hill slopes instead of infiltrating in the soil to recharge aquifers (Sharma 2003). This has left even high rainfall areas without water during the dry season. About 8.86 million ha (34.7% of the geographical area) of soil has degraded due to misuse and mismanagement of water resources and deforestation. About 600 million tones of soil is eroded from the region every year, carrying away a nutrients load of 1.4 million tones. Erosion and huge runoff from the hills is a major cause of floods in the region. Floods have severely affected the plains and their scale as well as frequency is increasing year after year (Borthakur, 1992). Total flood affected area in the region is 3760 km^2, while 35840 km^2 is prone to floods. About 64.3 % of the land is under forest cover in the region but the high rate of deforestation has jeopardized the water resources base. This has caused ecological imbalance in the northeastern region. Integrated management of water resources, therefore, assumes great significance. Since, shifting cultivation is the major culprit in misuse and mismanagement of water resources; alternate land use system, which must be sustainable and, resource and eco-friendly, are necessary to replace this age old practice.

Table 1. Crops / trees in different land use systems

Land use	Slope(%)	Crops / Trees	Livestock	Soil conservation measures
LU$_1$	32.0	Maize, rice-bean, oats, pea, guinea grass, tapioca, broom grass.	Cows, pigs rabbits	Contour bunds, trenches, grass water-ways
LU$_2$	38.0	*Alder nepalensis, Albziia lebbeck Acacia auriculiformis*	None	None
LU$_3$	32.2	*Ficus hookerii,* Eucalyptus, guava, pine, pineapple, french bean, pulse crops.	Goats ,rabbits	Contour bunds
LU$_4$	32.4	Beans, radish, maize, paddy, ginger, turmeric, ground-nut, oats, grasses on risers	Cows	Contour bunds, terraces & grass water-ways
LU$_5$	41.8	Beans, vegetables, guava, citrus, guinea grass, pineapple, ginger, *Alder nepalensis, Ficus hookerii*	pigs, goats	Contour bunds, bench terraces, half-moon terraces, grass water-ways
LU$_6$	53.0	Peach, pear, citrus, guava, lemon, vegetables.	None	same as in LU$_5$
LU$_7$	47.0	Mixed cropping		None

Alternate land use systems

Erosion and sediment transport are part of the natural evolution of the landscape and constitutes some of the most fundamental problems for the development of agriculture, water management, forestry and utilization of natural resources. The land use type has a considerable impact on the nature of runoff and related hydrological characteristics in the northeastern region. The rapid exploitation of natural resources has increased soil erosion and affected the health of ecosystem. While a large part of agriculture water consumption is inevitable due to the physical basic processes, there is a significant scope for improvement of in-field hydrological efficiency. A multidisciplinary study was, therefore, started in 1983 and is still in progress to judiciously manage rainwater and to improve agricultural productivity. It was based on watershed approach for different land use systems viz. livestock based (LU$_1$), forestry (LU$_2$), agro-forestry (LU$_3$), agriculture (LU$_4$), agri-horti-silvi-pastoral (LU$_5$), horticulture (LU$_6$) and shifting cultivation (LU$_7$) (Table 1). Different crops were grown in various land use systems, as per perceptions of the farmers, to give the full food security . The slope of the watersheds varied from 32 to 53%. Appropriate soil conservation measures were taken as per slope and nature of the crops grown. The surface and subsurface flow water was collected in a big pond dug-out at the foot hills. The run-off water was measured with measuring gauges installed at the base of each watershed and analysed for various nutrients and soil content as per standard procedures. About 99.1% of rain water was retained in livestock based land use system, followed by agriculture (95.2%) (Table 2). More retention of rainwater in the livestock based and agriculture land use system was due to the reason that soil surface coverage was more in these systems with the grasses, fodder and agricultural crops which helped in more infiltration of water in the soil. It was reported earlier also that more than 95% of rain-water can be retained *in-situ* by following these land use systems (Anonymous, 1990). Annual soil loss due to erosion varied from 0.16 to 8.03 tha^{-1} in new land use systems as against 45.1 tha^{-1} in the shifting cultivation. The N. P, and K content in the groundwater was considerably low in new land use systems as compared to shifting cultivation. Due reduced runoff because of proper vegetation cover and water and soil conservation measures undertaken, the soil loss was very low in the studied land use systems.

Table 2. In-situ recharge and soil loss from different watersheds (mean of 12 years)

Land use	In-situ recharge Input / (% of total output water yield)	Annual Soil ratio	Annual NPK loading loss (t ha-1) in ground water (kg ha-1)
LU1	99.1		0.16
	0.508		1.0:2.1
LU2	92.9		4.75
	2.436		1.0:1.6
LU3	94.5		1.90
	2.050		1.0:1.7
LU4	95.2		0.33
	1.675		1.0:1.9
LU5	94.9		0.47
	0.507		1.0:2.0
LU6	91.2		8.03
	3.440		1.0:1.7
LU7	66.3		45.10
	15.860		1.0:0.6

These land use systems could be adopted to replace shifting cultivation in the region depending on topography, slope and nearness to the market. The livestock based land use system can be adopted where demand for milk is there or market is near for disposal of the animal produce. Similar is the case with the agri-horti-silvi-pastoral land use system which has horticultural crops as its component.

The benefit / cost ratio was found to be highest in livestock based land use system and lowest in shifting cultivation. In shifting cultivation, the cost involved is higher than the returns from the system and as such found to be quite uneconomical. The benefit / cost ratio is likely to increase in forestry and agro-forestry land use systems when the trees mature and are ready for sale. With new sustainable and eco-friendly land use systems in place, the farmers have an alternative to leave shifting cultivation and go for settled cultivation. Maximum rain water could be retained *in-situ* and the soil can retain sufficient moisture for growing winter crops (Sharma, 2001). This would also helps in reducing runoff and soil loss and, better ecological conditions could be assured. The runoff water from the land use systems, collected in pond down the slope, is used for irrigation during winter as well as for rearing fish.

CONCLUSION

For integrated water resources management in northeastern region of India, it would be necessary to manage the rain water. The shifting cultivation prevalent in the region is a big constraint in the water resources management. The farmers of the region are not in mood, in general, to leave the practice since they are socio-culturally attached with it and secondly there are not alternate options to replace shifting cultivation. There is urgent need for ecologically sound, sustainable and productive land use system which may ensure maximum *in-situ* retention of rain water, reduce runoff as well as minimize soil loss. The results of the present study show that better options are available in the form of new land use systems studied, which fulfill above conditions and also have high benefit / cast ratio. There is need to popularize these land use systems under iso-agro-climatic conditions.

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Climate change and irrigation expansion: Land-water-atmosphere interactions in the Aral Sea basin

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Keywords: Aral Sea Basin, climate change, irrigation, hydrological modelling runoff, evapotranspiration fluxes, net water fluxes to the atmosphere.

ABSTRACT

The Aral Sea drainage basin (ASDB), covering an area of totally 1,874,000 km^2 in Central Asia, has experienced an enormous expansion of irrigated agriculture during the past century. Presently, water is diverted from the two principal rivers, Amu Darya and Syr Darya, to such an extent that the Aral Sea receives only about 10% of its former 70 km^3 annual freshwater input through river discharge. As a result, the Aral Sea started to shrink in the 1960's, and is expected to continue to shrink in the foreseeable future accompanied by desertification of surrounding areas. In addition to these water diversions, however, regional climate may also have changed significantly in the region since the 1960's as a regional manifestation of global climate change over this period. We investigate here land -water-atmosphere interactions in the Aral Sea basin using a basin-scale hydrological balance modelling approach, in which the locally created runoff (i.e., precipitation minus evapotranspiration) is estimated using precipitation and temperature as driving boundary conditions. The runoff is routed through a flow network derived from a 30"× 30" digital elevation model. Results show that the major irrigation areas in the ASDB yields a considerable 17% increase in evapotranspiration flux from land to the atmosphere, which is not balanced by a corresponding increase in observed precipitation. Despite the expected surface cooling effects of increased evapotranspiration, temperature data shows that the basin manifestation of global climate change appears to be a warming trend. In addition, our results show specifically that more than 90% of the irrigation water input in the ASDB returns to the atmosphere by evapotranspiration, which is at the high end of previous estimates. This indicates possible non-local and climate driving effects of water management that are relatively large.

INTRODUCTION

Recent studies indicate that land surface irrigation may have important effects on surface temperature and vapor fluxes to the atmosphere (Boucher et al., 2004; Gordon et al., 2005; Lobell et al., 2006; Kueppers et al., 2007). These effects may bias our understanding of and mislead comparisons between climate model projections and surface observations of greenhouse warming. Changes in evapotranspiration may also have important implications for water resource management by modifying the regional water use and transferring water from irrigated areas to other regions.

Large-scale irrigation effects on evapotranspiration and/or surface temperature have so far been studied by atmospheric (Boucher et al., 2004; Lobell et al., 2006; Kueppers et al., 2007) or land cover/use effect (Gordon et al., 2005) modelling with relatively low surface resolution and without consideration of the interconnections between evapotranspiration and inland water fluxes through the water balances of drainage basins. These interconnections imply that the large-scale model results can be checked against runoff observations and independent hydrological model results of water balance-controlled water and vapour fluxes on drainage basin scales.

The ASDB constitutes a unique possibility for such basin-scale hydrological quantification and check under conditions of both large irrigation and climatic change. The Aral Sea shrinkage started soon after major water diversions were made from the Amu Darya and Syr Darya rivers to irrigated agricultural fields. This commenced in the 1950's with the aim to increase cotton production. An estimated 700,000 km of irrigation canals were constructed until 1988 (Waltham and Sholji, 2001) and the largest, Karakum canal exports annually around 8 – 12 km^3 of water from the ASDB to other areas (Glantz, 2005). This is on the same order as the whole present Amu Darya discharge. As a consequence of these diversions, the river runoff into the Aral Sea decreased dramatically. Presently the Aral Sea receives only about 10% of its former 70 km^3 annual freshwater input through river discharge and it was occasionally more or less zero in the 1980s.

In addition to these water diversions, however, regional climate change in the ASDB since the 1960's may also have affected the hydrological cycle and the Aral Sea shrinkage. And to some degree, both the Aral Sea shrinkage itself (Small et al., 2001) and the mega-irrigation schemes in the region (Boucher et al., 2004; Lobell et al., 2006; Kueppers et al., 2007) may also have affected regional surface temperature and climate. The aim of this study is to quantify the relative and combined effects of regional irrigation and climatic change on evapotranspiration fluxes in the ASDB. The evapotranspiration quantification is possible with reasonable certainty because other main hydrological changes in this basin (precipitation, river discharge into and shrinkage of the Aral Sea) are measurable, large and essentially known (Jarsjö and Destouni, 2004), while more uncertain hydrological changes such as those in the submarine groundwater discharge into the Aral Sea are relatively small (Shibuo et al., 2006).

INPUT DATA AND MODELLING METHODOLOGY

Prior to the performed hydrological modelling, the basin was delineated (Figure 1) by constructing the entire topography-driven flow network into the Aral Sea using: Shuttle Radar Topography Mission data (SRTM, 2004), isobath data from Alekseeva et al. (2007), and information of stream locations in the Digital Chart of the World (DCW, 1992). The total basin area is 1,874,000 km^2, of which the individual Amu Darya and Syr Darya catchments constitute a major part, and smaller unmonitored catchment areas (most in the north) amount to a total area of about 321,000 km^2. The total basin area was discretised at a spatial resolution of 30"× 30".

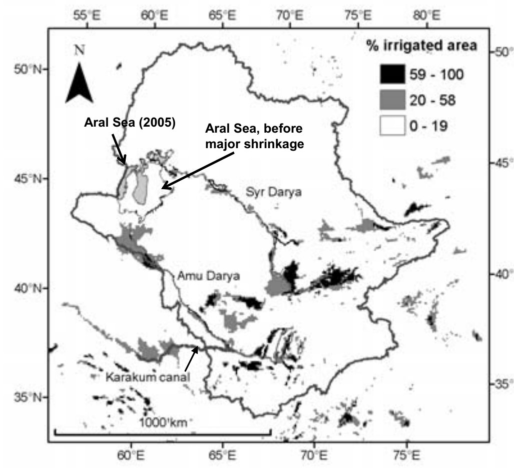

Figure 1. The Aral Sea Drainage Basin (ASDB) including the extent of the Aral Sea in 2005 and before its major shrinkage (DCW, 1992), the Amu Darya and Syr Darya rivers, main irrigated areas (grey scale reflecting the irrigated area fraction (Siebert et al., 2005)), and the constructed Karakum canal, which dominates irrigation water exports from the ASDB.

The hydrological modelling of the ASDB was carried out with the GIS-based PCRaster water flow model summarised in Jarsjö et al. (2004) and applied to a number of Swedish coastal catchments, among other catchments areas in Europe, for quantification of surface water and shallow groundwater flows (Jarsjö et al. 2004, 2006). The water flow model calculates the precipitation surplus as the difference between precipitation (P) and actual evapotranspiration (ET_a) in each cell and routes the precipitation surplus through topographically driven flow networks. The sum of precipitation surplus (P- ET_a) in each cell with area A, calculated as $\sum Q = \sum \left[\left(P - ET_a \right) \cdot A \right]$, constitutes the total modelled discharge into the Aral Sea. This discharge and the ET_a flux to the atmosphere are the investigated outputs of the model.

Actual evapotranspiration ET_a is estimated according to Turc (1954) as function of P and potential evapotranspiration (ET_p):

$$ET_a = \frac{P}{\sqrt{0.9 + \frac{P^2}{ET_P^2}}} \tag{1}$$

ET_p is calculated in each grid cell as a function of the annual average temperature (T) according to Langbein (1949) through the equation:

$$ET_P = 325 + 21 \cdot T + 0.9 \cdot T^2 \tag{2}$$

Generally, the considered water flow model requires slope direction, precipitation, temperature and percentage of irrigated areas as input to each grid cell. The annual average and spatially distributed P and T data for the whole ASDB was taken from the Climate Research Unit (CRU) TS 2.1 data base (Mitchell and Jones, 2005). Figure 2 shows the 20th century trends of the basin-averaged T and P observation data. The 20-year running T average exhibits a steady increase since 1950, just before the start of the dramatic Aral Sea shrinkage. The post-1950 average P is also somewhat greater than the pre-1950 average P.

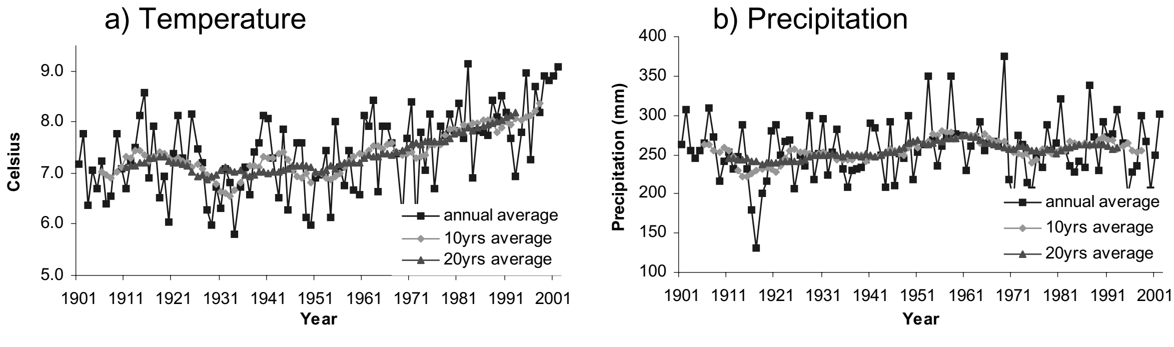

Figure 2. Temporal trends in reported a) temperature and b) precipitation data within the ASDB (Mitchell and Jones, 2005)

In order to model the post-1950 changes in the ASDB hydrology due to climate conditions and irrigation activities, the following simulation steps were followed:

First, scenario 1 (referred to as the natural scenario) was modelled. This scenario uses the temporal average T and P values for the period 1901–1950 as input and neglects irrigation activities. Before 1950 these activities were localized and relatively small compared to precipitation rates. Consequently, scenario 1 represents the relatively undisturbed hydrological conditions before the major influences of climate change and irrigation schemes occurred in the basin. This scenario is used for model validation under pre-1950 conditions. For this purpose, the resulting modelled Amu Darya and Syr Darya discharges are compared with reported river discharge data from two independent runoff data bases: one from personal communication with Mamatov (2004) and the other from the Global Runoff Data Center (GRDC) (2006).

Secondly, a hypothetical scenario 2 (referred to as the climate scenario) is modelled in order to investigate the possible recent 20-year (1983-2002) hydrological conditions that could have prevailed in the ASDB if only climatic change had occurred, without any effects of water diversions and irrigation schemes occurring at the same time. The reported P and T data averaged over the 1983–2002 period are used as input for this scenario.

Finally, the post-1950 combined irrigation and climate changes in the ASDB hydrology are modelled through scenario 3 (referred to as the climate-irrigation scenario). This is considered to be a realistic scenario for recent (1983-2002) conditions since it accounts for both the regional climate change and the major irrigation schemes. The total amount of irrigated water in the ASDB introduced into the model as additional precipitation is estimated through the difference between the scenario 2 discharge into the Aral Sea from the Amu Darya and Syr Darya catchments and the mean reported river discharge of scenario 3, and subtracting also the irrigation water exports, e.g. from the basin through the Karakum canal (Glantz, 2005). The obtained irrigated water input is then uniformly distributed as precipitation over the irrigation areas within each catchment and adjacent smaller catchment areas (grey areas in Figure 1), which were identified by the Global Map of Irrigated Areas (Siebert et al., 2005).

RESULTS

Table 1 summarizes the modelled river and other discharges into the Aral Sea and associated total evapotranspiration resulting from the three different simulated scenarios along with the average input data and validation/calibration data used for the whole ASDB. The modelled river discharges of scenario 1 are more or less similar to observed discharges from both main rivers. In addition, the modelled unmonitored (small streams and groundwater) flow to the Aral Sea is relatively small, which is consistent with previous estimates of pre-1950 conditions in the Aral Sea region (Björklund, 1999; Jarsjö and Destouni, 2004; Shibuo et al., 2006). These consistencies give some confidence in the modelled total evapotranspiration for the ASDB.

A comparison of the mean reported river discharge from the Amu Darya and Syr Darya catchments in the period 1983-2002 with corresponding modelled discharges from scenario 2 shows that the regional temperature and precipitation changes alone do not at all explain the observed river discharge decrease occurring in the ASDB in the period 1983-2002. Climatic changes alone lead rather to a 1% increase of river discharges, which is insignificant in relation to and masked by the large river discharge decreases implied by the engineered water diversions

Moreover, the about 1° C average temperature increase in the ASDB in scenario 2 yields a total evapotranspiration flux increase of about 18 km^3/year (4% change), from a pre-1950 value of about 391 km^3/year to a hypothetical present value of about 409 km^3/year. This 4% evapotranspiration flux increase from the ASDB to the atmosphere balances nearly fully the about 20 km^3/year (4%) precipitation increase into the ASBD.

The combined climate-irrigation scenario 3 yields, however, an evapotranspiration flux increase of about 49 km^3/year (about 12% change) relative to the hypothetical climate scenario 2, and 67 km^3/year (17% change) relative to the natural base scenario 1. The resulting evapotranspiration increase in scenario 3 relative to scenario 1 occurs primarily over the main irrigation areas in the south eastern part of the ASDB, where also precipitation has increased and temperature has increased less than in the north western part (results not shown here).

Table 1. Summary of input, modelled output and validation/calibration data in the three different simulation scenarios investigated in the ASDB. For the estimated water export through the Karakum canal (Figure 1), the maximum value within the reported range (Glantz, 2005) is used in order not to overestimate the modelled evapotranspiration flux.

			Scenario 1: Natural, 1901-1950	Scenario 2: Climate, 1983-2002	Scenario 3: Climate-irrigation, 1983-2002
Input data	Average temperature (ºC)		8	9	9
	Total precipitation (km^3/yr)		467	487	487
	Amount of irrigated water (km^3/yr)		0	0	50
Assumed or available reported data	Water export (km^3/yr) from the ASDB through:	Karakum canal	0	0	12[a]
		Other irrigation transfer	0	0	2
	Mean discharges into the Aral Sea (km^3/yr) from	Amu Darya	48[b]		8[c]
		Syr Darya	23[b]	n.a.	4[c]
		Total	71	n.a.	12
Modelled output data	Discharges into the Aral Sea (km^3/yr) from	Amu Darya	43	44	8
		Syr Darya	30	31	5
		Unmonitored	4	3	3
		Total	77	78	16
	ET flux (km^3/yr)		391	409	458

[a] (Glantz, 2005) [b] (GRDC, 2006) [c] (Mamatov, 2004)

DISCUSSION AND CONCLUSIONS

Our results indicate important effects of freshwater diversions and irrigation on regional water resources and climate in the ASDB. In total, the net water flux from the atmosphere to the surface of the ASDB (P-ET) appears to have decreased by 62% (from about 76 km^3/year in scenario 1 to about 29 km^3/year in scenario 3; Table 1), primarily due to irrigation. This indicates that the irrigation in the ASDB may also have non-local water resource and climate effects.

Non-local climatic effects of irrigated areas have previously been estimated by atmospheric modelling assuming an added evapotranspiration return flow to the atmosphere of about 40% of the irrigation water input (Boucher et al., 2004). This assumption yields considerably smaller estimates of evapotranspiration from the irrigated areas of the world (Seckler et al., 1998; Döll and Siebert, 2000; Boucher et al., 2004) than hydrological evapotranspiration assessments (Shiklomanov and Markova, 1987, as quoted by Milly and Dunne (1994) and Boucher et al., 2004; Gordon et al., 2005). The present results support the higher evapotranspiration estimates, by indicating a more than 90% return flow from the applied irrigation water in the ASDB. This implies possible relatively large non-local water and climate effects of the world's irrigated areas.

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Climate change impacts and adaptation in the hydrology of urban areas

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ABSTRACT

As heavy rainfalls are projected to become more common, while urbanization continues, one of the most vulnerable systems to the adverse impacts of heavy rainfall is likely to be urban storm water networks. Problems are associated with the design and implementation of storm water storages and flood routes.

Since precipitation varies considerably in space and time, its full range of variability and extremes may easily be missed by a rain gauge network. Therefore it was decided to study the intensity and frequency of short duration rainfalls using the nationwide weather radar data. An extensive amount of radar measurements provide a way to derive very large and significant samples of local precipitation climates. As "raw" radar measurements cannot be applied as such for quantitatively reliable precipitation statistics specific attention is paid to the quality control of radar data.

Baseline characteristics of precipitation events were calculated using continuously recording rain gauge data from the Helsinki-Kaisaniemi station. In addition, the temporal and spatial variations of heavy rainfall events were analysed based on conventional rain gauge measurements. Climate model simulations were used to estimate future changes in heavy precipitation. Further, two different kinds of 1D-2D hydraulic/hydrological models were used in distinct urban areas to study impacts and adaptation capacity of storm water systems.

The overarching purpose of this study was to update rainfall distributions used for design purposes, as well as to explore differences between new and old results on heavy rainfall distributions. Results show large differences between new and old heavy rainfall distributions in Finland.

INTRODUCTION

In Finland the most serious flood damage has been caused in the watercourses by melting of snow , by heavy rain, or both. During the last few years flash floods in urban areas caused by heavy rains have also become more frequent. Moreover, climate change has been anticipated to increase torrential precipitation. Therefore this project on heavy rains and urban flash floods called RATU was started.

There are various aspects connected with urban flash floods, for instance amount of water, quality, conveyance, responsibilities and legislation. When planning the project it was concluded, that primarily information on the amount of heavy rains should be made up-to-date. The main objectives of the project are:
1. To estimate the intensity and frequency of heavy rainfall for various time periods and areas
2. To evaluate the influence of climate change on heavy rains
3. To construct hydraulic models for two pilot areas and use the new data on rains in them
4. To evaluate the results of the project on urban planning

The advantage of weather radars compared to conventional gauge networks is the availability of measurements in real time, which exhibit typically 100 times better time resolution and 10 000 times better spatial resolution than national gauge networks. Consequently, extremely rare events can be detected in the data. On the other hand, the absolute accuracy of radar-based rainfall intensity in a randomly selected measurement bin is not very good. Much work has been devoted in removing systematic biases and random errors e.g. due to clutter and non-meteorological targets (Peura 2002) and sampling differences between gauges and radar (Koistinen et al. 2003) from the radar estimates of rainfall rate (R) and accumulated precipitation. In this study we present probability distributions of rainfall in areas of 1 km^2 - 1024 km^2 , the accumulation period ranging from instant to 24 h.

PRESENT CLIMATE OF HEAVY RAINFALLS

In order to assess how representative the occurrence of summertime heavy precipitation in 2000-2005 was compared to a standard 30-year period, two sets of rain gauge measurements were applied. The smaller set consisted of observational data at five stations in different parts of Finland during May-September in 1961-2005. The dataset was sectioned into three periods: 1961-1990, 1971-2000 and 2000-2005. For these periods, the following daily precipitation indices were analyzed: the mean, the relative frequency distribution, the 50th, 95th and 99th percentiles, the number of days with heavy rainfall ($R \geq 20$ mm/day), and the highest precipitation amount measured during each period. Compared to the standard period 1961-1990, the period 2000-2005 was fairly representative from many aspects of precipitation. It was thus inferred that the 6-year period can be applied in further precipitation extreme analysis, such as a survey of high-resolution data from weather radars. The same conclusion was made on the basis of rain gauge measurements at about 80 stations although a slight tendency towards a more frequent occurrence of days with $R \geq 20$ mm/day was found in southern Finland in 2001-2006 compared to 1971-2000.

In addition to these studies based on conventional rain gauges, rainfall data, collected with a continuously recording rain gauge at the Helsinki Kaisaniemi station, during the summers of 1951-2000, were used to examine the climatology of transient characteristics of precipitation, but no clear trends were detected. The longest rain event, the longest dry spell and the highest daily precipitation as well as all the intensities, studied from five minutes to 60 minutes, had their maximum in 1960. No new record values have been observed at that station since the summer 2000 until the summer 2006. As shown in Fig.1, the 10-minute mean rainfall intensities at that station exceed 1 mm/min approximately once in eight years and 2 mm/min once in 80 years (Kilpeläinen et al. 2007).

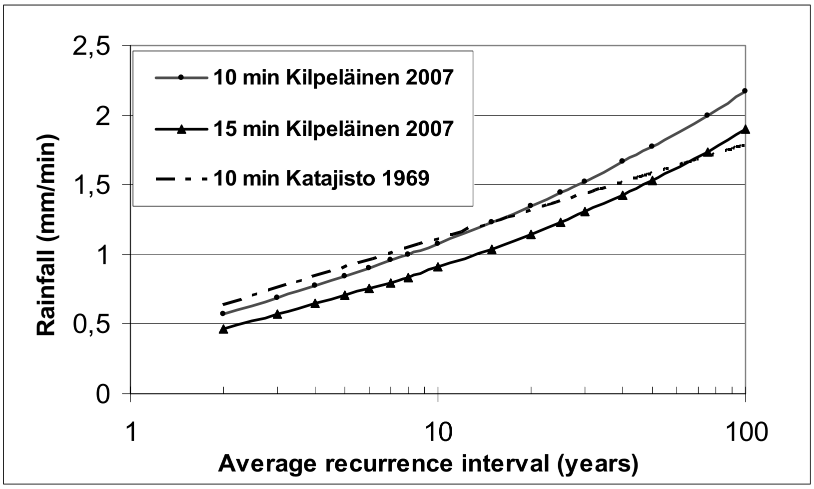

Figure 1. Current design rainfall frequencies in Finland (Katajisto 1969) compared to the results from Helsinki Kaisaniemi (Kilpeläinen et al. 2007).

WEATHER RADAR IN DEFINING HEAVY RAINFALLS

Quality control and processing of weather radar data. The Finnish C-band Doppler radar network of seven systems was used in this study. Time interval of archived data was usually 5 minutes. The major assumption made here is that individual measurement bins can be considered independent samples of precipitation. Specific attention was paid to the quality control and to the selection of the radar data sample to minimize the effects of various biases.

In this study we assumed that 10 dBZ (approximately 0.1 mm/h) is the lowest limit of radar reflectivity caused by rain. This threshold is mainly used to eliminate clear air echoes caused by insects and birds. To make the statistics representative in rainfall only, we have limited the data to the summer season i.e. May-September. Because the height of the freezing level is typically 1.5-3 km in summer, the radar beam meets sleet and snow regularly at longer ranges. Therefore all bins with a distance larger than 200 km from the nearest radar were excluded.

The amount of unpacked radar data in each phase of quality control and processing was of the order of 10 TB. The first step was to remove ground clutter by means of Doppler filtering in the signal processor. The second phase was to eliminate non-meteorological scattering from ships, sea, aircraft, external transmitters, birds and insects on the basis of pattern recognition and fuzzy logics (Peura 2002). Because it appeared to be difficult to remove sea clutter during anomalous propagation conditions and because we are mainly interested in rainfall over land areas, we neglected all bins located over the sea. Additionally, the algorithm for the diagnosis of hail by Holleman et al. (2000) has been applied in our data, to exclude all bins indicating hail.

New probability distributions of rainfall based on radar data. The archived raw radar data covering summers 2000-2005 consists of 8.5×10^9 measurement bins. After all quality steps and applying only the best bin in the areas or overlapping radar measurements the final data set consists of approximately 200 million measurement bins of radar reflectivity factor (Z) in rainfall. We converted that to rainfall intensity (R) applying a fixed R(Z) conversion (Dölling et al. 1998). Time-space variations in the average drop size distribution were assumed not to introduce any bias in the radar-based shape of the cumulative density function (CDF) of rainfall. The instantaneous areal radar bin measurement was transformed to a point intensity by assuming an average velocity of 10 m/s for rainfall patterns. On average, a radar bin measurement represents a 2- minute point measurement at ground level in the selected range interval of 30-200 km from the radars. Based on reference data, provided by three optical scatterometers of the type Vaisala FD12P, small statistical bias in radar measurements was removed.

The preliminary results show a good fit of the PDFs of radar-based instantaneous rainfall intensity to lognormal distribution, a result similar to those of e.g. (Kedem et al. 1994). The results also indicate reliable figures of the probability of very rare rainfall occasions (e.g. return period > 1000 years) that are practically impossible to detect with much smaller ground based rainfall sensor data. When the radar based CDFs are interpreted, on average, as 2 minute point intensities and compared to the Finnish gauge based hydrological "standard" figures the preliminary results suggest that the probabilities of high rainfall intensities (repeat time > 50 years) have been underestimated by a factor of two.

Finally we have repeated the CDF calculations for a set of area-intensities. The coverage area of the radar network was divided to squares of 1 km^2, 9 km^2, 100 km^2 and 1024 km^2. In these areas we calculated CDFs of the instantaneous rainfall intensity, as well as of the accumulation periods of 15 min, 1 h, 6 h and 24 h. These probabilities are then expressed as return period in years.

CLIMATIC CHANGE OF HEAVY PRECIPITATION

Increases in the frequency of heavy precipitation events have been observed over many regions of the globe during the latter half of the 20th century. The potential for intense precipitation is likely to futher increase in the warmer climate of the future, contributing to the growth of flood hazards in areas where inundations are typically triggered by heavy rain. Here we examine projected changes in the maximum one-day precipitation totals in Finland in May-September by the end of the 21st century on the basis of experiments performed with a set of regional climate models (RCMs, Christensen et al. 2007). The RCM experiments regionalized information from a global climate model, applying the IPCC-SRES A2 scenario. Most RCMs contained an atmospheric component only, the sea surface data and atmospheric lateral boundary values mainly derived from the global model.

The spatial patterns of projected changes are presented**.** The sea areas have been masked out, partly because of a rather unrealistic future climate over the Baltic Sea in summer in most of the model runs, arising from a very large increase in the Baltic sea surface temperature (SST) in the driving global model (Kjellström 2007). In one of the RCMs (REMO), lake surface temperatures are derived from the SST of the closest sea grid boxes (Hageman 2007). Consequently, REMO has very intense warming of lakes, which in turn leads to exceptionally high increases in mean and heavy precipitation in Finland during summer and autumn, compared to the other RCMs (Carter et al. 2005) Therefore we decided to neglect here precipitation data from that model for May-September and ended up using data from six RCMs.

Increases in the maximum one-day precipitation totals were projected in all seasons (Jylhä et al., 2007) and all summer months as well (Fig. 2). The multi-model mean changes in Finland by 2071-2100, compared to 1961-1990, are in general largest in July-August, ranging mostly between about 20 and 30%. Increases along the coastlines in Fig. 2 are partly exaggerated by the rather unrealistic future climate over the Baltic Sea, discussed above. Projected summertime growth in heavy precipitation is typically larger than that in mean precipitation (e.g., Jylhä et al., (2007). According to our results, days with heavy rainfall (R≥20 mm/day) will be more frequent in the future, and rare precipitation events (with of a long return period) are likely intensify, although for them random effects play a considerable role.

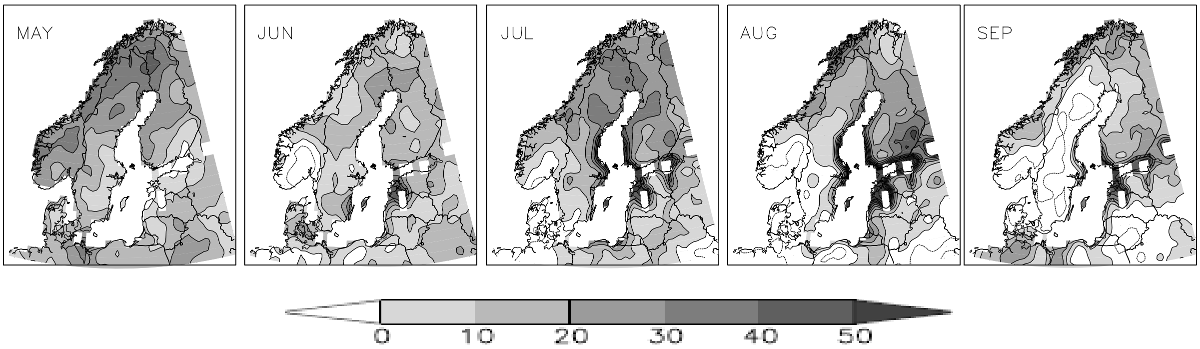

Figure 2. Projected changes (%) in the 30-year average of the greatest 1-day precipitation total in May to September for the period 2071-2100, relative to 1961-1990, as the multi-model mean of PRUDENCE RCM simulations with the A2 SRES scenario. Positive values are denoted by shading, negative ones by dashed contours, in both cases with an interval of 10%. Note that the values in Finland are positive but the large increases along the coastline in July-September are presumably overstated.

URBAN STORM WATER MODEL AREAS – IMPACT ANALYSIS

The impacts of above mentioned rainfall radar curves and climate change on runoff and other hydrological and hydraulic processes were analysed in two pilot areas located in the city of Espoo, southern Finland, next to the capital city Helsinki. Some properties of the areas are described in Table 1. These areas were selected because an extensive and still ongoing observation activity for urban hydrological cycle and water quality has been performed there. The analysis was timed only for defrosted period.

Table 2. Short description of rest areas in the city of Espoo (Laaksolahti, Vallikallio)

Area name	**Laaksolahti**	**Vallikallio**
Area type/Area [km²]	One-family houses/0.31	Blocks/0.13

Density of population [inhabitants per km²]	2 600	12 300
Elevation range in respect of sea level [m]	30-60	29-50
Average street slope weighted with street lengths [%]	4.0	1.9
Proportion of impermeable paved surfaces [%]	20	50
Length of storm water system [km] pipes/ditches	~1.0/~1.0	1,5/0
Storm water system built	Around 1981	1973-1993

Impact analysis was carried out with two models in Vallikallio, namely a non-commercial storm water modelling program developed by the TKK and the coupled MIKE SHE and MOUSE commercial models developed by DHI (www.dhigroup.com). The non-commercial, GIS-based, modelling program uses an event-based, distributed hydraulic model to simulate the rainfall-runoff process. It uses kinematic wave approximations and finite volume method in the routing model, Green-Ampt method in the infiltration model and Penman-Monteith method in the evapotranspiration model. The pipe flow is modelled with a linear storage function. In the MOUSE the hydrological cycle including the main losses infiltration and evapotranspiration is handled by MIKE SHE as well as 2-dimensional surface runoff. Roofs are however connected directly to storm water system, which is taken into account in the MOUSE as well as hydraulic modelling of the pipe flow. The model is a dual drainage model and surcharging water may exit the underground drainage system and re-enter it after a possible surface flow.

Preliminary results showed that the discharges in the observation point are increasing linearly when precipitation is increasing. It was also noted that existing elevation data from the area was originally inadequate for this kind of modelling and needed to be improved during the project.

ADAPTATION TO CLIMATE CHANGE

Finland's current heavy rainfall frequency information used in drainage planning is based on rain gauge data, that was published in 1969. The project concentrated only on urban storm water systems, though the climate change impacts have influence on roads, culverts and rooftops as well.

Possible adaptation measures for urban storm water infrastructure are according to Watt et. al. (2003):

- pipe replacement (under a normal maintenance program)
- disconnect impervious areas (roofs, parking areas)
- increase surface storage (soccer fields, schoolyards, ponds)
- reduction in rate of storm water input (reduce surcharge to sewer system)
- increase pond volume (availability of land)
- infiltration (depending on soil conditions).

Efficiency of adaptation measures varies geographically. Typically, in order to reduce peak discharge by 40 % one should disconnect impervious areas, and by 20 % one should increase surface water storage. By increasing infiltration it is possible to reduce risk of flooding, but not necessarily peak discharge, especially during hot and dry summer seasons.

Schedule of adaptation depends on expected climate change and current design of structures. Climate change is estimated to increase heavy rainfalls by 5-20 % within the next 20 years and by 20-40 % within the next 50 years in Finland. First, we should prioritize vulnerable systems and plan our schedule based on existing knowledge of climate change. This would require that by:

- 2010 we prioritize vulnerable systems and regions (previous floods, model studies)
- 2025 we increase surface storage or replace storm water pipes in normal maintenance program
- 2050 we disconnect impervious areas.

Very often structures such as culverts have been oversized, which helps to adapt to climate change, as it may not be necessary to replace structures before their life span ends. Evidently, it seems that after 2050, we should introduce new methods for urban storm water managers, in ordered to be able to adapt to further climate change.

CONCLUSIONS

Our results show a good fit of the PDFs of radar based instantaneous rainfall intensity to lognormal distribution. The results also indicate reliable figures of the probability of very rare rainfall occasions (e.g. return period > 1000 years) that are practically impossible to detect with a much smaller amount of ground-based rainfall measurements. The preliminary results suggest that the probabilities of high rainfall intensities (return period > 50 years) have been underestimated by a factor of two.

Adaptation requires prioritization of vulnerable systems and regions within the next 10 years. This would mean mapping of flood risk areas in urban regions and managing of flood risk. Within the next 30 years we should increase surface storage volume e.g. using storm water ponds and by 2050 we should disconnect impervious areas from storm water systems in urban areas. Situation is challenging as in urban areas trend is towards piping in Finland.

ACKNOWLEDGEMENTS

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Climate Change, Hydrological Extremes and Risk Management in the Himalayan-Ganga Basin

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Keywords: Climate variability, hydrological risks, extreme events, Himalaya, Ganga basin.

ABSTRACT

Climate change brings several impacts i.e. variable rainfall patterns, melting of glaciers, increased run-off, excessive flooding and water scarcity. Impending large variability in the monsoonal precipitation is likely to bring more extreme events and water scarcity problem. The melting snows and about 8000 glaciers feed several rivers, which sustain life of the plains. The Ganga basin is a large and crowded region with hundreds of millions of people who are highly dependent on large, international, and Monsoon-dependent river for livelihood security and other benefits in order to improve the quality of life. The annual rainfall ranges from 300 mm in the semiarid climate in the west to over 2000 mm in the east. In India, temperature increase was found mainly during post monsoon and winter seasons. The monsoon temperatures do not show a significant trend in any part of the country except for significant negative trend over Northwest India. Temperature shows cooling trend in the northeast and northwest India. Based on GCMs analysis, scientists suggest substantial increase of temperature and rainfall over India in next 100 years. In the present paper an attempt has been made to analyse the linkages between climate variability and water resources sustainability of the Gangetic plains. Finally, a risk management strategy has been incorporated based on responses of the community groups, policy makers and scientific communities.

INTRODUCTION

Mountains are the main hydrological and climatological triggers of the water cycle by presenting complex meteorological patterns. In terms of their role as water towers, mountain regions form an important supply of snow and/or rain-fed water to the lowlands. Glaciers feed most of the rivers, particularly in the Himalayan regions. These glaciers are very sensitive to their environment. They constantly change their shape and form to adapt with changes in the surroundings. While the relationship between climate and glacier mass balance is complex, the most important effect of recent global warming is the substantial loss of glacier ice that has occurred in all mountainous regions of the world, including the Indian Himalaya (Sen Roy and Singh, 2002). Most glaciers have thinned and their margins have retreated since the end of the Little Ice Age. Glaciers in many parts of the Himalaya have undergone significant shrinkage in the last century in response to climatic change, which in some areas is occurring faster than the global average. Gangotri, the headwater of river Ganga, is receding continuously at an alarming rate because of global warming as well as change in micro-climate.

In the present study, Himalayan-Ganga Basin i.e. upper part of river Ganga has been taken for study. The region lies in Uttarkashi district of Uttaranchal state. The Bhagirathi river system and Alaknanda river system meet at Devprayag to be called as Ganga thereafter Bhagirathi river originates from the Gaumukh, which is snout of the Gangotri glacier. As far as climate is concern, it varies according to height. It is quite diversified ranging from tropical to severe cold. For getting the secondary informations about glaciers, hydrological behaviours and associated hazards, the research works of several relevant governmental agencies have been analysed. Primary data collection involved a visit of the study area and getting first hand experience of the glacial and hydrological behaviour.

State of Climate Change in Himalaya

According to a 2001 report by the Intergovernmental Panel on Climate Change (IPCC), scientists estimate that surface temperature could rise by 1.4° C to 5.8° C by the end of twenty-first century. The increase in the global temperature in the twentieth century was observed as 0.6° ± 0.2° C (IPCC, 2001). This has started to affect the glaciers all over the world. The phenomena of global warming have already started showing its effect on the Himalayan glaciers. Globally, the 1990s were the hottest decade, and 1998 was the hottest year since 1861. Moreover, the seven hottest years since 1861 all fell in the 1990s. Around the world, glaciers are thinning and retreating and sea levels are rising. During the 20th century, the sea level rose by 10 cm to 20 cm (Brown, 2001).

A comprehensive analysis of ice core from glaciers make it possible to determine changes in the composition of the atmosphere and temperature over hundreds of years. Thus, glaciers are important element of nature, which respond to climate changes and provide knowledge of past, present and future climatic conditions of our globe. Gangotri glacier, the headwater of river Ganga, is receding at a rate of about 18 metres every year, due to a variety of reasons ranging from global warming to local factors. A large part of the discharge in the Ganga comes from the glacier rather than the monsoon rains. If the Gangotri glacier, which is among the biggest glaciers in the Himalaya, continues to recede at the present rate, a big hydrological disaster may occur.

RESULT AND DISCUSSION

Retreating Glacier

Glacier variation indicates global and/or local warming or cooling of the atmosphere. Study of the Himalayan glaciers has revealed various annual rate of retreat of the glaciers. Observations during the later half of the 19th century and early part of the 20th century led to the detection of various rates of glacial retreat in different parts of the Himalaya e.g. Bara Shingri of Lahul Himalaya (44 metres per year), Shankalpa-Kalabaland glaciers of Pithoragarh district (23 metres per year), Poting glacier of the same area (5 metres per year), Gangotri of Bhagirathi basin (18 metres per year) and Zemu of North Sikkim (8 metres per year). Almost all the glaciers of Himalaya and Karakoram are receding with varying rate (Table 1). Gangotri glacier, source of river Ganga is receding at alarming rate, which has adverse impact in Himalayan Ganga basin.

Most of the Himalayan Ganga Basin is mountainous in nature and also glaciated. Therefore, with changing climate these glaciated rivers can affect the downstream (Singh, 2004). The rate of retreat in recent times has, however, been much more rapid than the gradual retreat expected in an interglacial warming phase. Thus, glaciologists and climatologists believe, is due to global warming. Retreating nature of Gangotri glacier has been diagrammatically represented showing its snout map at different time (Fig.1).

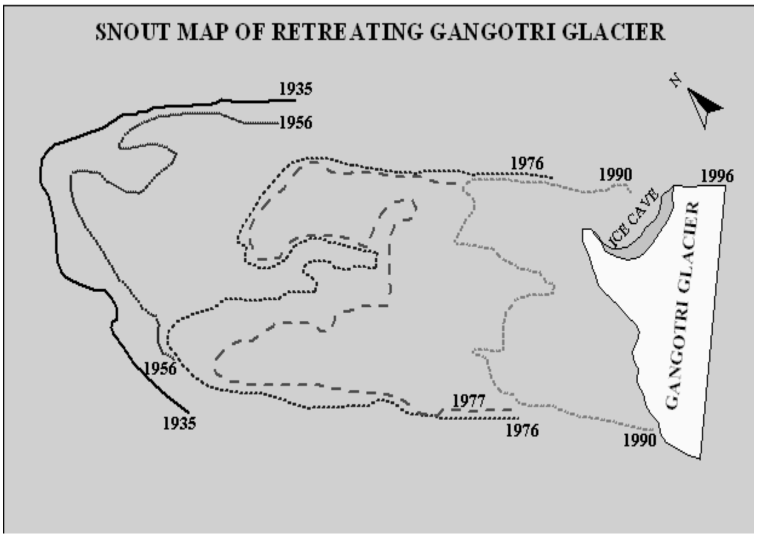


Fig.1 Source: modified after Sangewar (1998)

Table 1: Retreat of glaciers in Himalaya and Karakoram

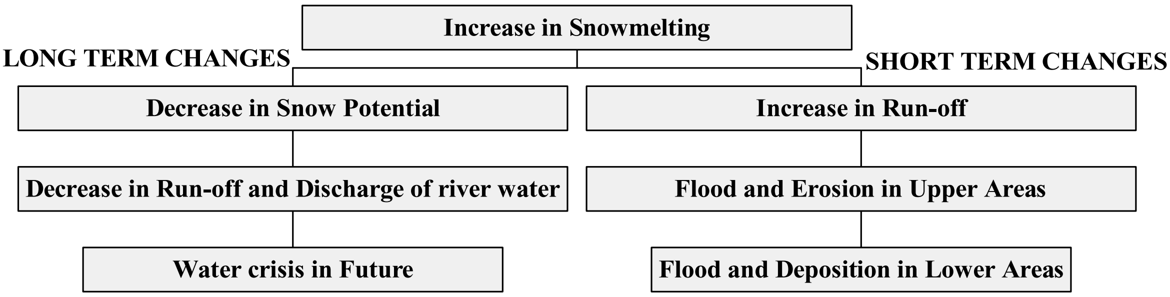
Mountain Range	Name of Glacier	Periods	Year	Total Retreat (metres)	Average Retreat (metre/ year)
Himalaya	Milam	1849-1957	108	1350	12.5
	Pindari	1845-1966	121	2840	23.5
	Shankulpa	1881-1957	76	518	6.8
	Poting	1906-1957	51	262	5.1
	Glacier No.3 in Arwa Valley	1932-1956	24	198	8.3
	Gangotri	1934-1976	41	600	14.6
		1962-2000	38	1341	35.4
	Zemu	1909-1965	56	440	7.9
		1975-1990	15	297	19.8
	Sonapani	1906-1963	57	905	15.9
Karakoram	Minapin	1906-1929	23	502	21.8
	Biafo	1861-1922	61	0	0
	Kichik Kumdan	1946-1958	12	1219	101.6
	Siachin	1929-1958	29	914	31.5
	Yengutsa	1892-1925	33	4134	125.3

Source: Vohra (1981) and Bahadur (2004)

Hydrological Extremes and Related Geohazards

Glaciers are the major sources of water in the Himalayan-Ganga Basin. Rapid rate of glacial retreat, because of global warming, increases the flow of water in beginning, causing flood situation in upland as well as lowland (Fig.2). But in long-term, rapid melting decreases the snow potential and thus create water crisis in future. Variable snowmelt may also interrupt the highland-lowland ecological symbiotic complexity.

Fig. 2. Impact of climate change



Exposed area near the snout is prone to numerous glacial geohazards like rockfalls, landslides, avalanches etc. Some of the most devastating effects of glacier meltdown occur when glacial lakes overflow and thus the phenomena of Glacial Lake Outburst Floods (GLOFs) take place, inundating the lowland areas. Various types of geohazards have been observed in the upper part of Himalayan Ganga basin. In addition, changes in sediment and water supply induced by climatic changes and glacier retreat have altered channel and floodplain patterns of rivers draining high mountain ranges. Loss of ice because of global warming has perturbed alpine geomorphic systems and created conditions that favour ice avalanching, slope failure, debris flow, catastrophic failures of moraine and glacier dams, it has also produced significant changes in the regime and platform of some rivers.

Garhwal Himalayan glaciers are having a thick debris layer on their ablation region. This is probably due to the heavy avalanching on the highly dissected steep slopes of the valleys. During the heavy monsoon rains (July to September) most of the debris is sluiced down through extensive longitudinal and transverse crevasses into subglacial channels in addition to basal sediment produced by processes of glacial erosion. The seasonal snow cover mainly sustains the drainage network in early summer. About the hydro-glaciological processes, the water and sediment in the Bhagirathi is derived from the glaciated valleys of the region, which receives enhanced level of precipitation orographically in winter from snowfall and from monsoonal rains during summer. The main processes of sedimentation in the Bhagirathi valley are non-glacial processes, which include the river damming/flooding, filling of the lakes and mass wasting. In high mountain regions, a number of natural catastrophes are related to glaciers, e.g., outbursts of glacier-dammed lakes or inter-glacial water reservoirs.

It is not only the reduction in length but also the thinning of its depth, which is a matter of concern. Quoting a 1998 study done by the UN Sponsored International Commission on Snow and Ice (ICSI) on the basis of satellite imagery, Hasnain (1999) mentioned that if the present scenario did not change, most of the Himalayan glaciers would disappear by 2035 A.D. Talking about flash flood, the study highlighted that the Malpa tragedy of August 1998, in which more than 200 people including 60 pilgrimages to the Kailash-Mansarowar, were washed away in the U.P. hills, were related to "Glacial Lake Outburst Flood (GLOF)" phenomenon. The rate at which smaller glaciers are disappearing leaving behind lakes, the next ten years in the Himalaya can be very dangerous. Thus, the hill regions of the country, characterized by a wide variation in physiography, geology, climate, flora and fauna and having varied socio-cultural traditions, are a unique geographical entity having one thing in common, i.e. their increased susceptibility to natural hazards (Singh, 2006). Other consequences of sea level rise due to excessive melting of ice are the saltwater intrusion. As sea level rises, salt water may invade coastal freshwater aquifers.

Risk Mitigation Strategy

Monitoring of glaciers is important to assess future availability of water resources in the Himalayan region. In the coming decades, potentially dangerous lakes are expected to form on many glaciers, which will also enhance the phenomena of paraglacial activities like landslides, debris flow and avalanches, and resources in Himalayan regions may be insufficient for the necessary mitigation works (Owen and Sharma, 1998). Therefore, there is a growing need for a long-term view of evolving glacial/hydrological hazards in the region, based on sound understanding of the life cycle of these glaciers and their response to climate changes. The permanent reservoir of glacier ice is enormous in the Himalaya. Therefore, a detailed database is required on seasonal and permanent ice cover along with establishment of a hydrological network with measurement of climatic variables over the range of altitudes.

In order to control and minimize the extreme events, it is necessary to analyze those geohazards. Proper information systems with sound techniques need to be developed and therefore research work must be taken up to identify the critical regions, which are at risks due to changing nature of climate. The fragile mountainous area is particularly prone to numerous types of hazards. Any comprehensive attempt to reduce environmental hazards depends on a sequence of steps being taken by the concerned decision- makers. The first rational step must be to identify the hazard and to estimate risks and its consequences. Once the hazard has been identified, it is possible to adopt response strategies to control the hazardous processes (Singh, 2006). It is essential that we act now to mitigate the climate changes and thus its effects on hydrology. We must, therefore, adapt to ensure that we can manage the additional risks associated with these impacts. Identifying and using appropriate sectoral tools and an integrated assessment approach with adequate data inputs can lead to improved assessments with reduced uncertainties. Further refinements can be achieved if the human dimensions of climate change are also addressed with a focus on regional and sub-regional vulnerability as well as adaptation. In order to achieve such levels of assessment research, there is a need to enhance technical and institutional capacity to understand, analyze and address climate change.

Forest department has taken some initiatives regarding the afforestation programme, though it has to be accelerated with the participation of local people. In Gangotri-Gaumukh region i.e. in the upper reaches of Ganga basin, some afforestation programmes are going on by governmental organizations, NGOs and local people. Some indigenous technologies like metal caps to protect the tender plants from frost are also being utilized.

CONCLUSION

Thus, uncertainty and variability in climatic conditions in the Himalaya also influences water resource sustainability. Hydrological problems of high Himalayan region are associated with its inherent fragility due to immature geology and extreme weather and climatic conditions. These regions are regularly exposed to earthquakes, landslides, forest fires, avalanches, flash floods etc. Mostly the reasons are natural yet their intensity and frequency increase manifolds due to human induced activities. The inventory will be useful for assessing hydrological impacts of global climate change and for prediction of future glacier and sea level trends. The possibilities for economic transformation, both within and adjacent to the Himalaya, are enormous if any part of the water volume can be stored, or diverted, and distributed more uniformly in space and time. Any such processes, however, must be integrated with an understanding of the regional environmental and social conditions. Recent initiatives of the Government of India regarding Interlinking of Rivers requires careful geographical enquiry in order to mitigate extreme events.

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Combined grid-based and conceptual approach to climate change impact estimation for water resources planning

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Keywords: Turc model, monthly water balance model, water resources planning, climate change impact, GCM scenario, changes in annual and mean monthly runoff.

ABSTRACT

For climate change impact studies for planning purposes robust and simple models are required, which allow for the evaluation of alternative scenarios in ungauged basins and are less data intensive. In the paper a two-step methodology is proposed for this case. First the potential impact of climate change on the long-term mean annual runoff is evaluated using a simple grid based annual water balance model. This model is based on the Turc formula; it is calibrated for whole Slovakia and is using grid maps of runoff, temperature and precipitation as inputs. The model can be used at ungauged sites to evaluate annual climate change impact scenarios including incremental scenarios for sensitivity analysis. In the next step pilot basins are chosen as representatives for various types of long-term mean monthly runoff distribution. A conceptual hydrological balance model is used for modeling climate induced changes in runoff with monthly time steps in these. In the second stage of the proposed method, the simulated long-term mean monthly runoff from the pilot basins is used as a disaggregation pattern of the long-term mean runoff in basins with similar runoff regime to represent changes in the seasonal distribution of runoff due to climate change. The approach is tested in the Flysh Region of Slovakia.

INTRODUCTION

The impacts of climate change on hydrological processes are usually estimated by defining scenarios of changes in climatic inputs to a hydrological model from the output of general circulation models (GCMs). A series of uncertainties are introduced in course of this procedure. Among these are the primary sources of GCM uncertainties (like those about the future concentrations of greenhouse gasses and aerosol emissions), further the uncertainties about the sensitivity of the change of the global climate assessed by different GCMs (because of the way the physical processes and feedback mechanisms are simulated within the various GCMs), and uncertainties about regional climate changes due to differences in the results of different GCMs for the same intensity of global warming. Additional uncertainties are introduced by downscaling methods which have to be used to overcome the limitation and temporal mismatch between GCM outputs and inputs of hydrological models (interpolation techniques, statistical downscaling and downscaling of the output of GCMs and regional meteorological models). Further uncertainties result from the coupled runoff simulations and may be due to errors in the GCM simulation and the hydrological simulation, from the inadequate representation of the physical processes (model and parameter errors) and the non-climatic data used to drive the hydrological model (data error). Properly conducted climate change impact studies are therefore data and method intensive and as such not always suited for preliminary assessments of climate change impact needed in the first stages of water resources planning studies. Moreover detailed climatic input data and physiographic catchment characteristics, which are required for climate change impact modeling, may not be available or feasible to be collected for water resources planning studies in real life situations, when models have to be used in ungauged basins. Therefore robust and simple approaches are required, which allow for the evaluation of alternative scenarios in both gauged and ungauged basins and are less data intensive.

In the paper a two-step methodology is proposed for this case. First the potential impact of climate change on the long-term mean annual runoff is evaluated using a simple grid based annual water balance model based on the Turc formula. It is calibrated for whole Slovakia and is using grid maps of runoff, temperature and precipitation as inputs, thus it can be used at ungauged sites to evaluate annual climate change impact scenarios. In the next step pilot basins are chosen as representatives for various types of long-term mean monthly runoff distribution. A conceptual hydrological balance model is used for modeling climate induced changes in runoff with monthly time steps in these. In the second stage of the proposed method, the simulated long-term mean monthly runoff from the pilot basins is used as a disaggregation pattern of the long-term mean runoff in basins with similar runoff regime to represent changes in the seasonal distribution of runoff due to climate change. The approach is tested in the Flysh Region of Slovakia. Combination of both models allows for two-step robust impact estimation for planning purposes.

METHODS

For modelling changes in the spatial distribution of specific runoff, raster-based hydrological balance models are often used. The issue of the raster interpretation of mean annual runoff has been addressed by many authors (e.g., Gottschalk and Krasovskaia (1997), Arnell (1995)). In Slovakia, Szolgay, et al. (1997) and Parajka (1999, 2000) have dealt with mapping long-term mean annual runoff. For modelling the spatial distribution of changes in the long-term mean annual runoff in Slovakia, an empirical raster-based model was developed. It is based on the Turc model, which represents the hydrological balance equation between the long-term mean annual runoff *O* [mm], the long-term mean annual precipitation totals *Z* [mm] and an index of the potential evapotranspiration *EPI:*

$$O = Z.\left[1 - \frac{EPI}{\left(1.168.EPI^{3.273} + Z^{3.273}\right)^{1/3.273}}\right] \tag{1}$$

where *EPI* is evaluated according to an empirical relationship as a function of the long-term mean annual air temperature *T*. The regional parameters of the model for Slovakia were estimated using runoff and precipitation data from the period 1951−80. Here several empirical relationships were compared to the original Turc empirical model for the estimation *EPI* in Equation (1) (see Figure (1)). *EPI* was computed by the Tomlain-Budyko method in 54 climatic stations.

The values of the long-term annual runoff in equation (1) are considered as point values (elementary runoff) and are spatially interpreted in a GIS as a grid map of specific runoff. As inputs to the model, raster maps of the long-term mean annual precipitation totals and the long-term mean annual air temperature are used. Long-term mean annual specific runoff is estimated in a GIS by spatially integrating the specific runoff estimated by equation (1). The *EPI* models were validated against measured long-term mean annual runoff in 13 basins representing various runoff regimes with basin area ranging from 90 to 2000 km^2 and long-term mean annual runoff from 173 to 600 mm. It can be seen from Figure 2, that all the new empirical models perform comparatively with respect to runoff generation, only the original Turc model is biased (probably also due to the different period used for its calibration). Since in the climate change impact studies the mean annual air temperature is usually extrapolated beyond observed values, here the refitted Turc model was selected, because it is believed that its form, expect the offset for the data from Slovakia, the inherited the general behavior *EPI* on the northern hemisphere in the original model. To avoid further problems with extrapolating outside the range of air temperatures used in the derivation of equation (1), which could occur for future climate conditions, it was decided to restrict its validity to altitudinal zones which would not exceed this limit under changed climate in this study (it requires catchments between 500 and 1600 m a.s.l.).

For estimating the changes in the seasonal runoff distribution, a conceptual monthly water balance model developed at the Slovak University of Technology is used (Hlavčová, Kalaš & Szolgay 2002). The model conceptualises a river basin as two nonlinear reservoirs, and it simulates the water accumulation in the basin *z*, snowmelt, evapotranspiration, runoff from impermeable areas, surface and subsurface runoff and baseflow using empirical and conceptual relationships. The distinction between solid and liquid precipitation is made on the basis of threshold temperatures. The inputs required for the modelling of the water balance in a monthly time step are: the mean monthly precipitation for the basin, the mean monthly discharges in the outlet of the basin and the mean monthly potential evapotranspiration (*PET*). Evapotranspiration *EV* is a function of the *PET* and the catchment storage state *z*. For calculating *PET*, the Tomlain-Budyko, Thornthwaite, Ivanov and FAO methods can be used and additional climate data (the mean monthly hours of sunshine duration, the long-term mean monthly values of the relative air humidity, and the mean monthly air temperature values) are required. In the model a genetic algorithm (GA) is built in to calibrate the 11 model parameters, and the Nash-Sutcliffe criterion is used as an objective function.

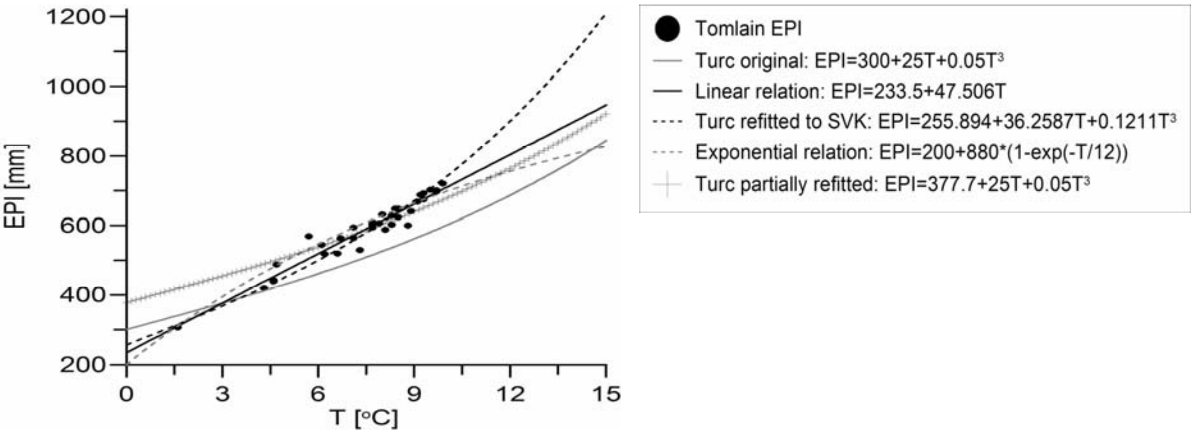

Figure 1. Empirical models of the index of long-term mean annual potential evapotranspiration *(EPI)* as a function of long-term mean annual temperature *(T)* in 54 meteorological stations

Runoff regimes and their classification have received increase attention in the recent past, e.g. Krasovskaia, Arnell and Gottschalk (1994) reported on the development of procedures for classifying flow regimes and Krasovskaia (1997) has published a series of studied on the stability of river flow regimes and proposed an entropy based grouping of river flow regimes. The monthly and seasonal variability of the flow regime of Slovak rivers was regionalised by logical reasoning in Šimo and Zaťko (1980) into 5, and Turbek and Škoda (1989) into 14 categories, respectively. Hanušin (2000) used quantitative regime characteristics and physiographic catchment descriptors to classify and map monthly flow regimes. Parajka (2005) used cluster analysis to group similar within the year distribution of long-term mean monthly flows into 7 pooling groups. All regionalisations enable the classification of ungauged basins, but are mutually not quite consistent. Therefore here the selection of test catchments was restricted to the Flysh Region. This area usually occurs as homogeneous within most hydrological regime regionalisations. The Flysh Region is located on the outer belt of the West Carpathian Mountains range. It consists of two parts - West and East Flysh region, which are divided by Tatry Mountains, which belong to the high core mountains. The geology of the area is characteristic by impermeable sedimentary rocks consisting of mainly calcareous clays and sandstones. The impermeability of these formations causes rapid surface runoff resulting in minor groundwater accumulation and the occurrence of many small flushes and some mineral springs.

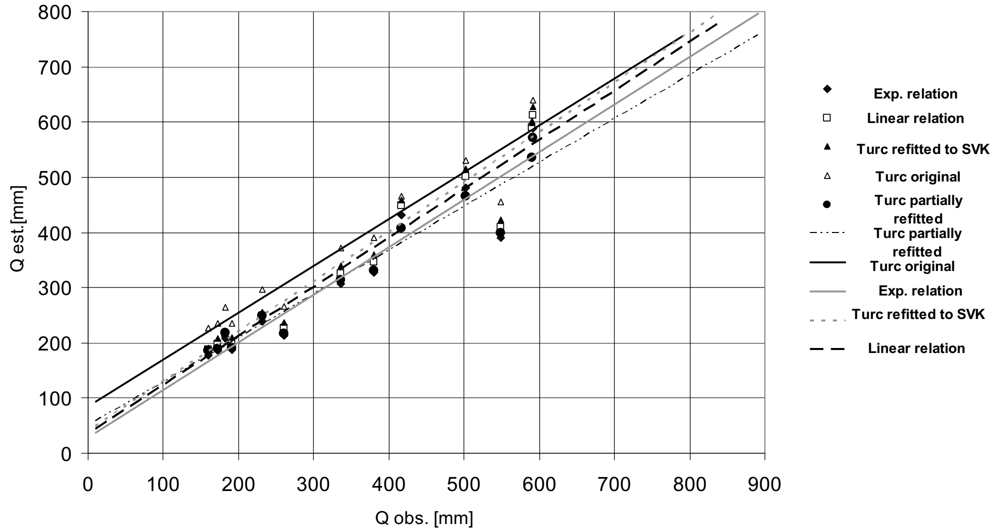

Figure 2. Comparison of observed and estimated runoff long-term mean annual runoff in 13 basins for the five empirical relations for the computation of *EPI* (see Fig 1.) in Equation (1)

RESULTS

To test the proposed two stage procedure the outputs of the CCCM97 coupled ocean and atmosphere general circulation model were used as downscaled for the Slovak National Climate Program (Lapin, et al., 2001). The scenarios were given as changes in the long-term mean values of the monthly and annual precipitation and the air temperature for the time horizons 2010, 2030 and 2075. Data in four catchments were available for this study in the Flysh Region. Two, the Kysuca and the Biela Orava River, are at relatively higher elevation near the Polish-Czech border and belong to the Western Flysh. The others, the Torysa and the Topla Rivers, are located about four hundred kilometers eastward in the East Flysh Region and have a lower mean elevation. The basic physiographic data of the basins are given in Table 1. The Orava catchment and partially the Kysuca fit into the required altitudinal zone, the Topla and Torysa catchments do not.

Table 1. The basic physiographic data of the pilot basins

Basin - section	Mean basin elevation (m a.s.l.)	Lowest point (m a.s.l.)	Basin area (km^2)	Mean air temperature (^{0}C)	Measured runoff ($l\ s^{-1}\ km^{-2}$)
Biela Orava - Lokca	866	619.06	356	5.4	19.2
Kysuca - Cadca	641	408.36	493	6.5	17.1
Torysa – Kosicke Olsany	510	187.83	1298	7.2	6.3
Topla - Hanusovce	437	160.71	1049	7.6	8.4

The proposed procedure was tested in two steps. In the first step the performance of the model for the long-term mean annual runoff was verified. The monthly model is considered to be a better conceptual representation of catchment evapotranspiration than the semi-empirical Turc equation in this study; therefore it serves as a basis for comparison in the changed conditions. Given the well developed altitudinal zonality of precipitation, air temperature and runoff and the expected altitudinal shift of flow regimes and water balance constituents due to climate change, to test the ability of the annual model to predict the future water balance constituents, two contradictory requirements were set up:

1. it was tested, if in catchments within the elevation zone, where equation (1) can be expected to hold even for changed climatic conditions, the annual and the monthly water balance models give comparable estimates of the change in the long term mean annual runoff,
2. it was tested, if in catchments outside the elevation zone, where equation (1) is expected to hold, the decrease in the long-term mean annual runoff as predicted by equation (1) overestimates that predicted by the monthly model (due to the cubic extrapolation in the refitted Turc model beyond the limit of 10 degrees).

The consistency of the outputs of the monthly model was also tested. It was expected, that in catchments belonging to the same regional runoff regime type, the within the year distribution of the long-term mean monthly runoff remains similar under climate change (since the climate change scenarios do not show significant differences in both parts of the Flysh Region).

Table 2. The inter-comparison of the percentage of change in the long-term mean annual runoff under climate change as predicted by the annual and monthly model

Basin-section	Annual model			Monthly model		
Time horizon	2010	2030	2075	2010	2030	2075
	(%)	(%)	(%)	(%)	(%)	(%)
Biela Orava - Lokca	-0.2	1.3	-2,8	-0,3	1.7	1.8
Kysuca - Cadca	-2.8	-1.2	-6.5	-3.3	-1.7	-5.0
Torysa – Kosicke Olsany	-6.0	-5.0	-16.4	-6.3	-4.4	-6.9
Topla - Hanusovce	-4.8	-3.7	-13.8	-0.1	1.1	0.1

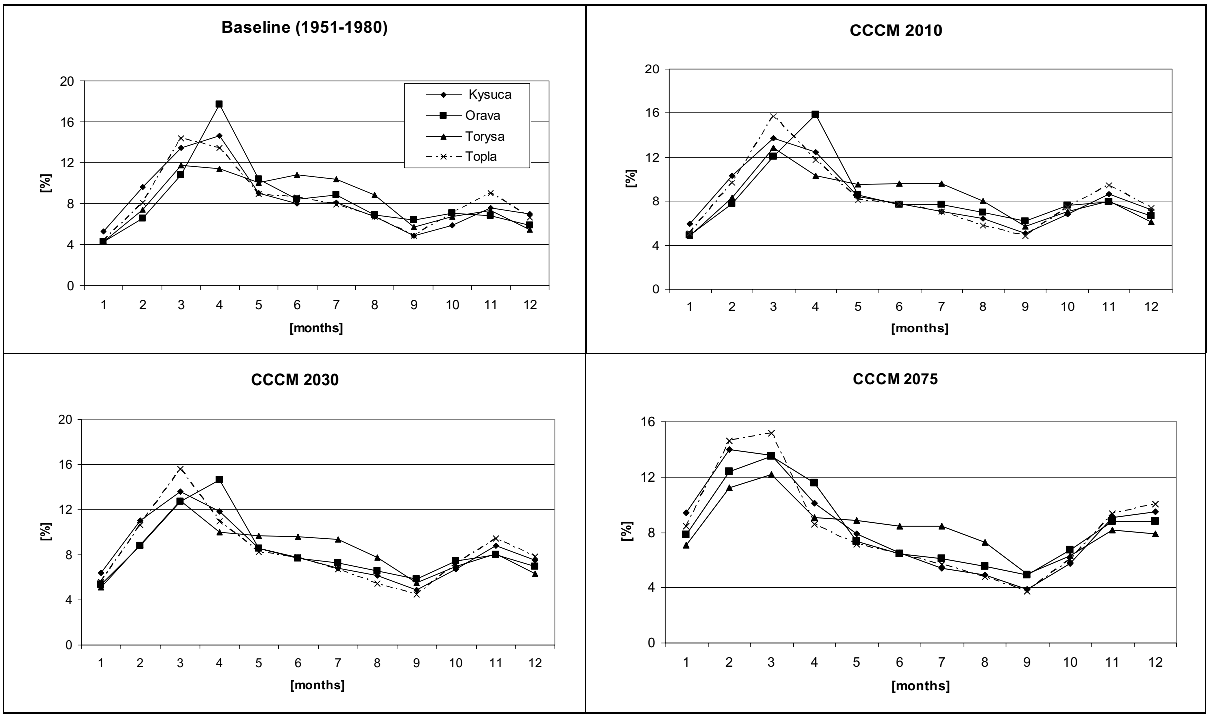

Figure 3. The within the year distribution of the simulated long-term mean annual discharges of the baseline period and under changed climate expressed as percentage of the simulated long-term mean discharge in the four rivers from the Flysh Region

Table 2 contains the inter-comparison of the change in the long-term mean annual runoff under climate change from both models and Figure 3 shows the within the year distribution of the scaled simulated long-term mean annual discharges. It can be seen, that in the Kysuca and Orava catchments the predicted changes by both models are quite consistent (one has to consider, that the changes are relatively small when expressed in millimetres) as for the direction and the order of magnitude of the change for 2010, 2030 and 2075; for the Topla and Torysa catchments this does not holds. Especially for 2075 the predictions are not consistent, since the air temperature increase by the CCCM97 scenario is too high for equation (1) to be valid. The within the year distribution of monthly runoff remains similar in all four catchments for the changed conditions regardless of the altitude so they will belong to the same regional type of monthly runoff distribution. This similarity is utilised in the proposed two step procedure for the disaggregation of the long-term mean runoff into mean monthly flows in catchments from the same regional type.

CONCLUSION

In the paper a robust and simple two-step methodology was proposed for climate change impact studies for planning purposes, which allows for the evaluation of alternative scenarios in ungauged basins. First the potential impact of climate change on the long-term mean annual runoff was evaluated using a simple grid based annual water balance model. This model is based on the Turc formula; it was calibrated for whole Slovakia and is using grid maps of runoff, temperature and precipitation as inputs. It was shown, that the model is capable to reproduce runoff under the present and moderately changed climate. In the next step pilot basins were chosen as representatives for various types of long-term mean monthly runoff distribution and a conceptual hydrological balance model was used to model climate induced changes in runoff with monthly time steps. It was shown, that in the pilot basins the seasonal distribution of runoff does not change in the course of climate change. Therefore in the second stage of the proposed method, the simulated long-term mean monthly runoff from the pilot basins can be used as a disaggregation pattern of the long-term mean runoff in basins with similar runoff regime to represent changes in the seasonal distribution of runoff due to climate change. The approach was tested in the Flysh Region of Slovakia. For the future other homogeneous regions will also have to be included in the testing and a procedure for estimating annual potential evapotranspiration index for the Turc model, which will be valid beyond the range of measured mean annual rainfall and air temperature data in Slovakia.

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Examples of summer spatial variability patterns for phreatic levels associated to the ENSO event, by the Empirical Orthogonal Functions (EOF) method

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Keywords: ENSO, precipitation, phreatic, summer variability

ABSTRACT

Numerous examples of spatial variability patterns were determined with the help of the one-point correlation method. Parts of these spatial patterns were determined by the Empirical Orthogonal Functions method (EOF) for the phreatic levels summer seasonal means for non-grid data.

Other patterns were obtained using not-only the standardized Southern Oscillation index (SOI) index, but also the Darwin and Tahiti pressure indexes.

This one-point correlation method helps us to locate the high and low areas of variability of phreatic levels and also allows the estimation of spatial patterns during summer and during other particular months (November).

In terms of contribution to the total variability of summer phreatic levels, the major source of variability is due to precipitation and to the changes in surface pressures associated to El Niño - Southern Oscillation (ENSO).

In the case of an extreme (ENSO) event, these similar spatial patterns for seasonal phreatic data allow us to foresee particular areas where the impact associated to the ENSO event is extreme, useful later for risk studies assessments.

INTRODUCTION

The paper is intended to give an impression of the response pattern of phreatic levels system from an unconfined aquifer(free-pressure aquifer) located at mid latitudes in summer season to the free atmosphere pressure forcing and to emphasize the qualitative pattern of ElNiño-Southern Oscillation (ENSO) and in particular to realize a difference between North Atlantic Oscillation (NAO) type pattern from the ENSO type patterns for the phreatic levels system (without the purpose of an objective intercomparison patterns method proposal). ENSO represents one of the most important modes of variability at decadal time scale followed by NAO, which is the second source of variability and influences precipitation and temperature in the Northern Hemisphere. Several studies link rainfall to NINO3.4 (Mariotti et al. 2002) for the spring season or the SON SST 3.4 (a "precursor" of the ENSO event) to the precipitation anomalies (Buermann et al. 2003), it was established a positive correlation between precipitation (0.4). This positive correlation is the meaning of the precipitation excess associated to ENSO. The link Northern Hemisphere spring surface level pressure (SLP) with NINO3 was realized by authors (1873-1995) (Oldenborgh et al. 1999), they found a negative correlation (-0.3) between these two parameters and 0.2 correlation winter NINO3 and spring precipitation. As known, Southern Oscillation Index (SOI) index is associated to the ENSO and measures the strength of the event. For summer and winter seasons, ENSO conditions influence the risk of very warm or very cold seasons (Wolter et al. 1999), ENSO has some influence in determining the probability of dry and wet seasons in Europe/Spain (Diaz & Rodrigo 2005).

METHODS

Possible ENSO influences on precipitation and temperature at midlatitude are due to the main atmospheric circulation cells (Wang, 2005), the relationship of precipitation and temperature to warm/cold phases is nonlinear (Shabbar et al.1997). The ENSO events are “warm” or “cold” based on the methodology of the CPC NOAA center based on historical SST data, where warm/cold episodes of ENSO are defined based on threshold of +/-0.5^{0}C for the resulting index after the 3 order running mean smooth of SST anomalies in the region Niño 3.4 (5^{o}N-5^{o}S, 120^o-170^{o}W), for the period 1971-2000. The warm/cold ENSO events are defined for when the termic threshold is realised for a period of minimum 5 consecutive over-lapping seasons (Shabbar et al.1997 and the Cold and Warm episodes by season 2007). The SOI standardized index is in positive dependence with the precipitation at Debrecen (21^0.63’E, 47^0.48’N) (PPD) in august (0.73) and 0.46 with the annual precipitation anomalies (not figured) as in Figure 1 a),

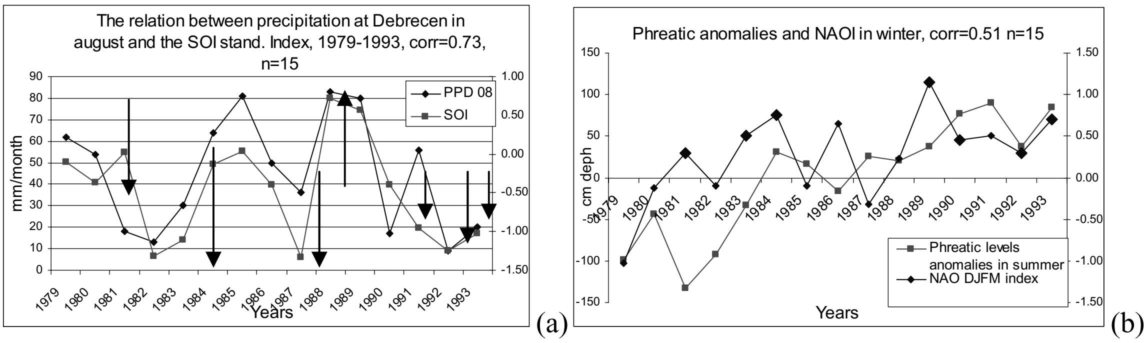


Figure 1. SOI index leads the PPD 08 corr=0.73 ENSO warm phase years are: 80, 83, 87, 91, 92, 93(down arrow) and cold phase is 1988(up arrow) (a); NAO major events are realized in the years 81, 83, 84, 89, 90, 92, 93(with mark), cor=0.51(b). (Notation: Climlab2000 soft data base-notation “SOI” (computed as Tahiti-Darwin sea level pressure), CPC NOAA center-notation “SOI CPC”).

and the phreatic anomalies are positive correlated with the NAOI from winter (the Figure 1 b) when NAOI index increases (associated to drought), the phreatic anomalies are increasing. It seems that the major contribution to the total variability is due to North Atlantic Oscillation (NAO) which explains only a part from the total variability of phreatic levels as it will be shown further on. This approach is possible due to the classical Empirical Orthogonal Function (EOF) method frequently used for climatic parameters (precipitation, temperature) variability analyses. Here, the EOF classical method (applied with a -specialised soft ClimLab2000 to standardised data) is applied to a data set formed by monthly summer means (June-July-August) phreatic levels from aleatory monitor wells not-influenced by rivers, by their emplacement (located in interfluvia) from the low-land region in the North Western part of Romania.

RESULTS

The main results of the EOF method are the EOFs are presented the 1 to 3 EOFs (Figure 2 a-c) spatial patterns , the PCs in Table 1 and and the eigenvalues (the real values) in Table 2.

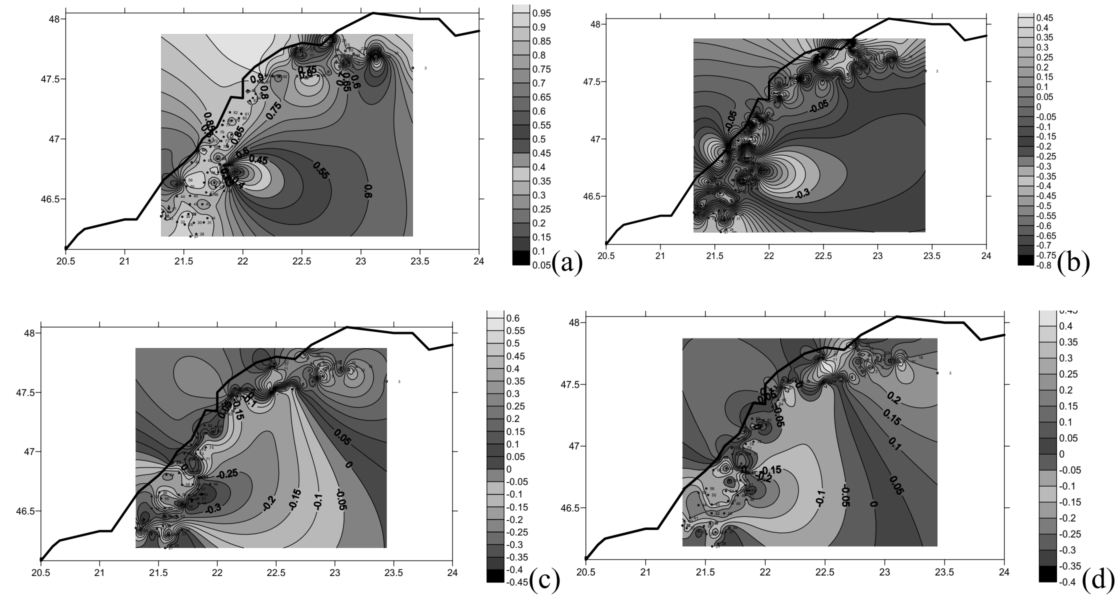


Figure 2.The EOF1 (a); the EOF2 (b); the EOF3 (c) and the SOI 11 CPC previous year pattern (d).

In Figure 3d is presented the spatial pattern of the SOI 11 CPC previous year pattern very similar with the EOF3 (Figure 3c).

Table 1. First 6 principal components (cm depth)

Factor	PC1	PC2	PC3	PC4	PC5	PC6
1	-71.42	-4.85	2.15	-0.84	1.57	-0.41
2	-113.95	9.7	-1.23	-4.13	-0.41	1
3	-71.34	-9.75	5.43	-0.75	-0.15	-1.49
4	-81.04	-6.81	-1.53	-0.06	-2.08	0.48
5	-8.98	-11.18	-0.4	3.19	-3.01	0.91
6	27.77	-5.47	-4.97	5.37	-0.14	-1.2
7	-17.8	4.59	-10.26	2.48	4.15	1.76
8	-9.57	-0.24	0.34	0.76	3.53	0.18
9	-10.99	6.86	4.78	-0.46	0.01	-1.3
10	14.82	0.81	3.63	-1.63	1.1	-0.21
11	14.71	11	-8.64	-0.93	-4.36	0.19
12	129.25	-11.08	-5.63	-6.79	0.65	-0.39
13	56.12	8.73	0.3	1.71	-0.07	-4.24
14	58.09	6.22	10.77	0.76	-0.11	1.14
15	84.32	1.48	5.26	1.32	-0.67	3.57

Table 2. First 14 real eigenvalues, the standard error, the explained variance and the cumulated variance for 14 eigenvalues

Ordered eigen-values	Eigenvalues	Standard error	Explained Variance	Cumulative variance
λ1	64.24	23.46	71.7	71.7
λ2	7.5	2.74	8.37	80.06
λ3	5.5	2.01	6.14	86.21
λ4	2.82	1.03	3.15	89.35
λ5	2.11	0.77	2.36	91.71
λ6	1.69	0.62	1.89	93.6
λ7	1.6	0.58	1.78	95.38
λ8	1.23	0.45	1.37	96.75

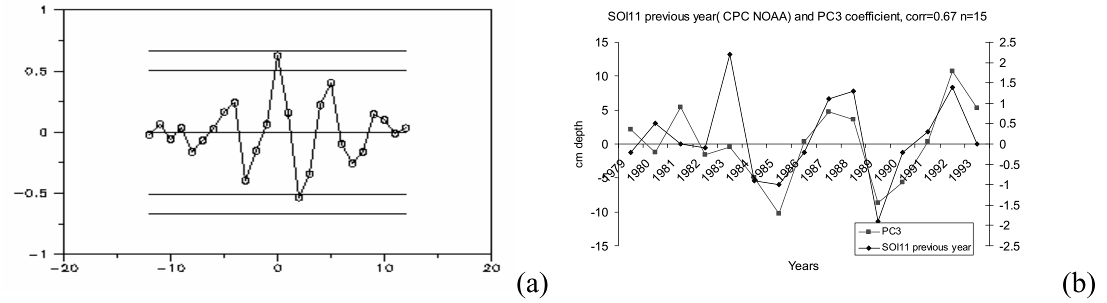
λ9	0.76	0.28	0.85	97.6
λ10	0.63	0.23	0.7	98.3
λ11	0.49	0.18	0.55	98.85
λ12	0.41	0.15	0.46	99.31
λ13	0.32	0.12	0.36	99.67
λ14	0.3	0.11	0.33	100

A method used to identify spatial patterns at continental scale is the one-point correlation method applied for phreatic levels annual means consisting in the simple correlation with the time series which lead to various spatial patterns. There are considered 96 monitor wells (the water pressure is atmospheric at any point of their phreatic surface) and 15 years for the period study. It is defined a warm event index (WEI) by the sum of warm events of a year divided by the total warm ENSO events in the analysed period (79-93). In order to check the existing correlations with the principal components, there are computed the cross-correlations (Table 3) (under the assumption of normal distribution of phreatic levels). Significant results (>0.56 are realised especially for the third component Figure 3 and Figure 3b for the lag 0 correlations).

Table 3. The 100xCorrelation coefficients between the main principal components 1 to 6 and the pressure indices based WEI

Cross-correlation of temporal coefficients with the warm ENSO index *													
Lag time	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
PC1	-22	-6	27	26	12	21	11	29	24	34	15	1	23
PC2	25	-18	-24	-1	34	-19	17	-3	33	-11	21	41	11
PC3	17	39	24	-26	-68	9	47	45	-51	-63	16	83	36
PC4	-36	-19	13	12	-7	-12	25	29	13	-56	-21	-1	11
PC5	40	-20	-53	-17	17	44	-16	-17	-19	39	26	-11	-47
PC6	-8	-17	-4	-8	14	-13	-13	21	34	0	-71	-14	59

(*The statistic significance is computed using the confidence interval: +-NORPPF (1-0.5*α), α is the confidence level, NORPPF is the standard normal percent point function).



(a) (b)

Figure 3. Cross-correlation plot SOI 11 CPC previous year and PC3 for summer phreatic levels (a); and same correlation at lag-time 0 statistic significant at CL 95% is 0.67 (b).

For the analyzed time-domain, the regime of phreatic levels was influenced by precipitation above normal after ENSO years as following: after 1987 and 1991 the levels are lowering after 1982, 1986, 1987, 1991 the levels follow the same behaviour, tend to rise in absolute value. After major El Niño events the precipitation anomaly is reducing; after LaNiña year the levels are descending (here 1988 is a LaNiña year). Phreatic levels descend slightly in time (Figure 4a) and record an extreme low value/minimum in 1981 (Figure 4b).

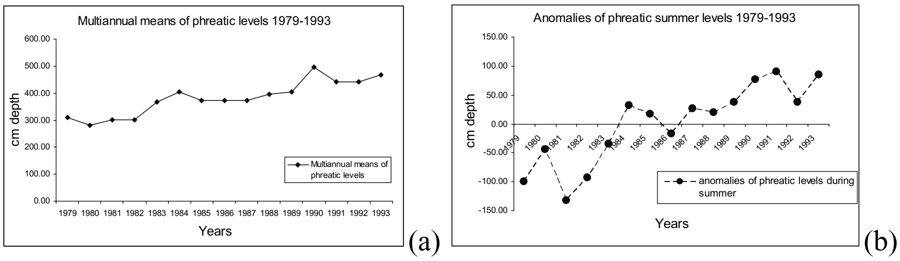


Figure 4. The multiannual means of phreatic levels (cm depth) (a); The anomalies of phreatic levels during summer season (b).

There are presented in Table 4 and Figure 5 other similar patterns determined with the one-point correlation method between various pressure indices and the phreatic levels with interest in the region of wells (numbered with 1 to 25 for the Somes-Tisa hydrographic space and 26 to 96 for the Crisuri hydrographic basin).

Table 4. Pair of similarities between spatial patterns due to different pressure indices ("-" means opposite sign and SOIp is the SO index for SOI standardized values >1)

Pair of similarities	
Pressure index spatial pattern 1	Pressure index spatial pattern 2
WEI 1982	NAO JJA
EOF3	SOI11CPC
-Darwin 11	SOI11
Tahiti 08	SOI 08
-SOI08	WEI, Darwin annual index, SOIp(-)
Darwin 11 previous year	NAO08
SOI 11 previous year	Tahiti 11 previous year

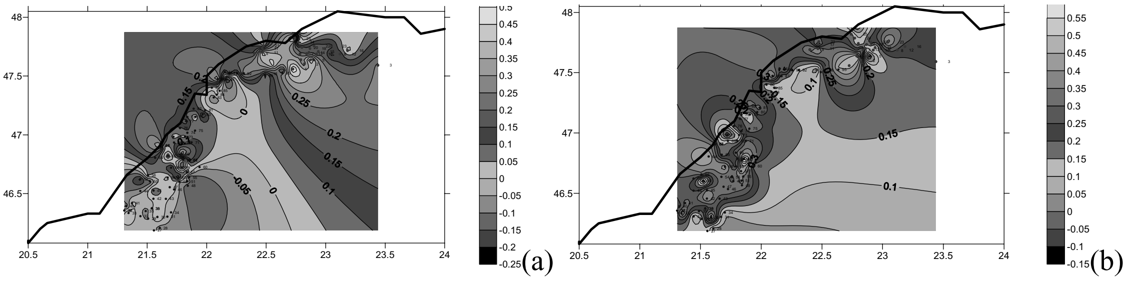


Figure 5. The spatial pattern of Darwin 11 pressure index (a); the spatial pattern of NAO 08 pressure index (b).

The time dependencies between the first 4 principal time coefficients and the various pressure indices is used in multivariate methods in order to predict the main state evolution of the initial variable(the phreatic levels). The main correlations are due to the SOI11CPC (0.67) followed by NAOI in summer (0.52) and NAODJFM (0.55) as figured in Table5

Table 5. The simple correlation EOFs and pressure indices SOI type and NAO type

	NAOI	SOI11CPC	SOI11	NAODJFM	D11	T11
EOF1	0.52	-	-	0.55	-	-
EOF2	-	0.34	0.34		-0.29	0.34
EOF3	0.46	0.67	-0.44		0.38	-0.44
EOF4	-	-	-		0.46	-

Empirical modeling of phreatic anomalies by linear regression models is suggested by the EOF method itself, applied for the "reconstruction" of summer seasonal anomalies time series with the first two components usually preferred for regression. On the base of the 6 EOFs base is proposed the following simplistic linear fit:

$$anom_{JJA}(t)=\sum_{i=1}^{6} PC_i(t)*X_i$$

This model becomes: $anom\ JJA(t)=0.88*PC1+3.74*PC2-1.62*PC3+1.27*PC4+0.41*PC5+0.14*PC\ 6-0.208*10^{-2}$ with the fit parameter $R^2=0.94$. A multivariate approach for simulate phreatic levels multiannual means may be realized with predictors indexes from Table 3 (the technique is described in Jury (1999) for the selection of multiple parameters and the algorithm of the method), this model lead to less better fit results (not presented here).

DISCUSSION AND CONCLUSIONS

SOI index drives PPD (Figure 1a) and is useful in delineating ENSO events from NAO events as result from the EOF analysis. NAOI spatial pattern is similar with the patterns of phreatic during warm, neutral and cold phases of the ENSO and with the multiannual means spatial pattern, with no significant differences and during summer; the NAO pattern is similar with the cold phase pattern. The EOF3 pattern which explains ~6% from the total 100% variability and the SOI11 pattern (Figure 2d) for the wells of unconfined aquifers (aquifers with free levels) presents similitude; the pressure based indices SOI08, Darwin index and SOIp index have spatial patterns pair similarities with the EOF3 mode. The temporal pattern of the component PC3 is well described by the SOI11CPC index (Figure 3b). Not only the SOI indexes are useful in the spatial pattern analysis, but also the Tahiti and Darwin pressure indices: thus, the November indices SOI11 and Darwin11 have similarities with opposite sign and Tahiti 08 and SOI08 indices spatial patterns are also similar. The spatial pattern due to the Darwin November previous year index is almost identical with the NAO08 index spatial pattern. With the EOF method, the delineation NAO from ENSO patterns is possible from a qualitative and quantitative point of view. The EOF method is useful in the reconstruction of initial phreatic anomalies time series and with the help of the first six principal components is realized a good linear fit model ($R^2=0.94$).

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Monthly climatic water balance of the Apulia region (Southern Italy): analysis of historical weather data and the projections for the 21st Century

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Keywords: climate change, precipitation, evapotranspiration, climatic water balance, Southern Italy.

ABSTRACT

This work is focused on the analysis of historical weather data of the Apulia region (Southern Italy) and the projections for the 21st Century. The historical weather data include monthly values of precipitation and minimum and maximum temperature measured at 162 meteorological stations in the period 1951-1990. Monthly climatic water balance is estimated as a difference between precipitation and reference evapotranspiration. Reference evapotranspiration is estimated by Hargreaves approach from temperature data and latitudes of meteorological stations. Data are analyzed by means of 10-years average values to find out the trend of the mean temporal variation of weather variables throughout four decades, from 1951-1960 to 1981-1990. The results have demonstrated a significant decrease of annual precipitation, in the range of 22.5%, corresponding to an average yearly amount of about 167 mm. The greatest reduction of precipitation was observed in January (50%) and May (39%). A slight decrease in maximum air temperature and a minor increase in minimum air temperature, both in the range of 0.5°C were observed over the four decades. This provoked an average decrease of evapotranspiration on yearly basis of about 57 mm. The overall results have shown that the climatic water deficit in the region has increased, on annual basis, on average by 110 mm.

The climatic water balance for the 21st Century was based on the projections of the GCM (scenario A2) elaborated by Hadley Center (UK). The overall results indicated that by the end of 21st Century could be expected an increase of temperature in range between 1.3 and 2°C. The reference evapotranspiration would follow the similar trend with an expected increase of about 15.4% when averaged over the whole region. The precipitations should not change significantly in the next 100 years on a yearly basis although a slight decrease in summer months and a slight increase during the winter season are expected. The climatic water deficit would increase over the whole region, on average, by more than 200 mm. The greatest increase of water deficit is foreseen for the Capitanata region, one of the most important agricultural areas.

INTRODUCTION

The evidence of climate change at global and regional scale has been confirmed in several Reports of Intergovernmental Panel on Climate Changes during the last years (IPCC, 2001; IPCC, 2007). Agriculture, industry, human health and settlements, environment, and land and water resources are all undergoing the effect of the climate change, and a large amount of studies are being carried out to investigate the possible consequences and measures to counteract the undesired outcomes. The assessment of results for the Mediterranean region indicates that summer temperatures are likely to increase more than global mean and that annual precipitation is very likely to decrease. Accordingly, the last IPCC Report (2007) pointed out that the risk of summer drought is likely to increase in the Mediterranean area. However, there are many uncertainties related to the prediction of regional climatic scenarios and assessment of the corresponding effects and risks (Christensen et al., 2007).

This paper presents some of the results of investigations on climate variability and changes carried out at the Mediterranean Agronomic Institute of Bari in the last years. The studies are related to the variability of main weather variables (air temperatures and precipitations) in the past (Todorovic and Steduto, 2002) and to the projections of their variation throughout the 21st Century (Burcak, 2002). The analysis is performed for the Apulia region and it is based on monthly climatic water balance.

MATERIALS AND METHODS

The Apulia region is situated in the eastern part of Southern Italy and comprehends a surface area of approximately 19,500 km^2. The region is relatively long (350 km) and narrow (60 km), extended from NW to SE. The region borders with the Adriatic sea on the East and the Ionian Sea on the South, while the western and Northern part partially border with the uplands and hills of the Apennine massif.

The climate is predominantly of the semi-arid Mediterranean type with hot and dry summer and mild and rainy winter season. The annual precipitation ranges from 400 to 600 mm on most of the region, and it reaches up to 1000 mm only in the central part of Gargano. In the most part of the region, hydrological regimes are irregular, of torrential type with high flow rates during the rainy season and practically no water flow during summer.

In the analysis are used two data sets: a) the historical weather data for a period of 40 years taken for 162 stations from the Italian National Hydrographic Institute and b) the projected climatic change data for the 100-years period procured from the UK Hadley Center for Climate change. Historical weather data are obtained for the period from 1951 to 1990 and include monthly values of precipitation and minimum and maximum temperature at 162 meteorological stations located in the Apulia region and its surroundings (Figure 1). These data set was examined for error detection and spatial and temporal integrity during the previous investigations. The missing precipitation data were estimated at all locations by using the double mass analysis (Steduto et al., 1999).

The projected climate data were estimated by HadCM3, a coupled atmosphere-ocean general circulation model developed by Hadley Center (UK). The model provides comprehensive mathematical description of the important physical elements and processes in the atmosphere, oceans and land surface comprising the climate system. This model has been used by the Working Groups of the Intergovernmental Panel on Climate Change for the realization of Special Report on Emissions Scenarios (SRES) and in many other studies (The Scientific Basis; www.Hadleycenter.uk web site).

The data sets applied in this work are related to A2 SRES scenario which assumes heterogeneous world, self reliance and preservation of local identities. In this scenario, the fertility patterns across regions converge very slowly and population is increasing continuously. The A2 scenario represents more pessimistic situation than other SRES scenarios like A1F1 and B2.

The projected data include monthly precipitation values and minimum and maximum temperature of all over the world, while for this study are used only the data referring to three cells falling in the area of interest and indicated in Figure 1. The cell's size is about 300 x 278 km comprehending a surface area of approximately 83,400 km^2. The coarse resolution of the HadCM3 model output data creates difficulties since the values attributed to four cells represent average climatic conditions of each cell and they could not be representative at regional scale where local variability of climate can be significant due to variations of altitude and topography, distance from the coast, land use, etc.

Historical data measured at 162 meteorological stations for the period 1950-1990 are used as initial database and these data set is extended for the period 1990-2100 on the basis of expected climate changes estimated by HadCM3. The relationship between the fine scale (meteorological stations) and coarse scale (HadCM3 cells) data is based on the territorial appurtenance of meteorological stations to one of three cells (i.e. the expected variation of climate at each meteorological station is a function of the projected climate change for overlaying cell) as illustrated in Figure 1.

The downscaling of information from a coarse scale grid (hundreds of km size) to a detailed-scale grid (couple of km size) has been done in such a way to contain the information from both scales:

the high resolution parameters of spatial variation at the regional scale (e.g. measured values of climatic variables at various locations) and the coarse resolution of climate change trend at the global scale (e.g. GCM data). The downscaling from global to regional scale is performed on the monthly data set averaged on the 10-years basis. Thus, the projected variations of air temperature and precipitation estimated by HadCM3 is averaged for each month on the 10-years basis. These variations are converted in percentage variations from decade to decade for each cell and, then, they are integrated (i.e. projected) to the initial database containing precipitation and temperature measured at each meteorological station over the 40-years period (1950-1990). In such a way, a regional database for 162 meteorological stations is created containing the measured average monthly values of minimum and maximum temperature and precipitation for the period 1950-1990 (labelled for the whole period with the middle year 1970) and projected monthly values of same variables for 10-years periods starting from 1990-2000 (labelled with the middle year 1995) and ending with 2090-2100 (labelled with 2095). Then after, these data are spatially interpolated over the whole region by using the Kriging method. This is a stochastic optimal interpolation method, frequently used for interpolation of both weather and soil variables.

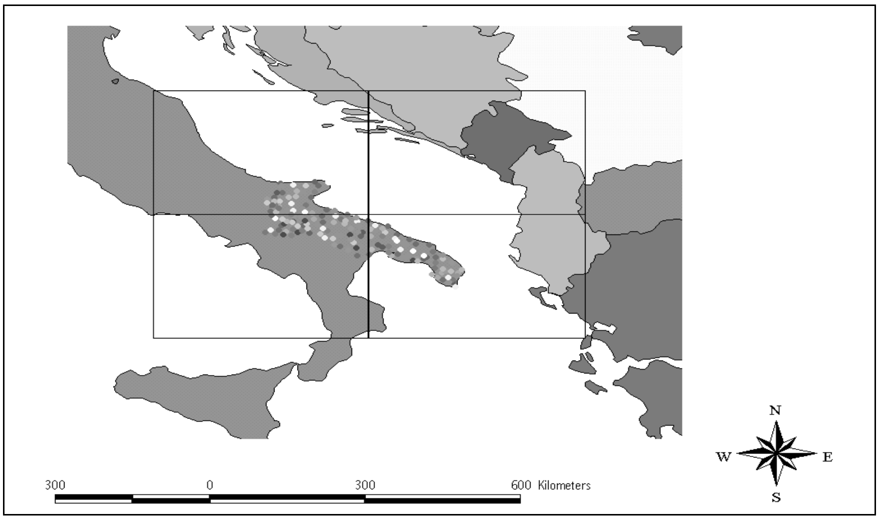


Figure 1. The locations of meteorological stations used in analysis and the cells corresponding to the projected climate change data (HadCM3)

Reference evapotranspiration was calculated on monthly basis by Hargreaves approach (Hargreaves and Samani, 1985). This method is a simple empirical equation, which uses as an input, beside the minimum and maximum air temperature (Tmin and Tmax, respectively) also the values of extraterrestrial radiation (Ra). The following form of Hargreaves equation is applied:

$$ET_o = 0.0023\frac{R_a}{\lambda}(T + 17.8)(T_{\max} - T_{\min})^{0.5} \qquad (1)$$

where λ is the latent heat of vaporization, T is an average air temperature in °C, and multiplier (0.0023), exponent (0.5) and the value of 17.8 in the third multiplier of the equation are the parameters-constant values.

Subsequently, the Climatic Water Deficit was calculated on monthly basis as a difference between reference evapotranspiration (ETo) and precipitation (P):

$$CWD = ET_o - P \qquad (2)$$

RESULTS AND DISCUSSION

The overall results of analysis of the historical weather data emphasized a significant decrease of annual precipitation, in the range of 22.5%, in the period 1950-1990. This corresponds to an average yearly amount of about 167 mm, i.e. from 742 mm/year in the period 1951-1960 to 575 mm/year in the period 1981-1990. On a monthly basis, the greatest reduction of precipitation was observed in January (50%) and May (39%), and then in November, October and April (about 29%). The analysis of temperature data indicated a slight decrease in maximum air temperature and a minor increase in minimum air temperature, both in the range of 0.5°C over four decades. Such a variation in air temperature provoked an average decrease of evapotranspiration on yearly basis of about 57 mm, which is equivalent to 5.4%. As a result, climatic water deficit in the region has increased, on annual basis, on average by 110 mm. Spatial analysis of data has indicated that the uplands of Gargano area and Apennine slopes, located in the North-West of the region, were the most prone to weather changes and to extension of water deficit.

The precipitation (P), reference evapotranpiration (ETo) and Climatic Water Deficit (CWD) data are averaged over the whole region for the period 1950-1990 and for all decades for the period 1990-2100. The annual variation of P, ETo and CWD in the past and for the 21st Century is summarized in Figure 2, while a comparison of monthly precipitation and reference evapotranspiration data for the period 1950-1990 and the last decade of projected values 2090-2100 is given in Figure 3.

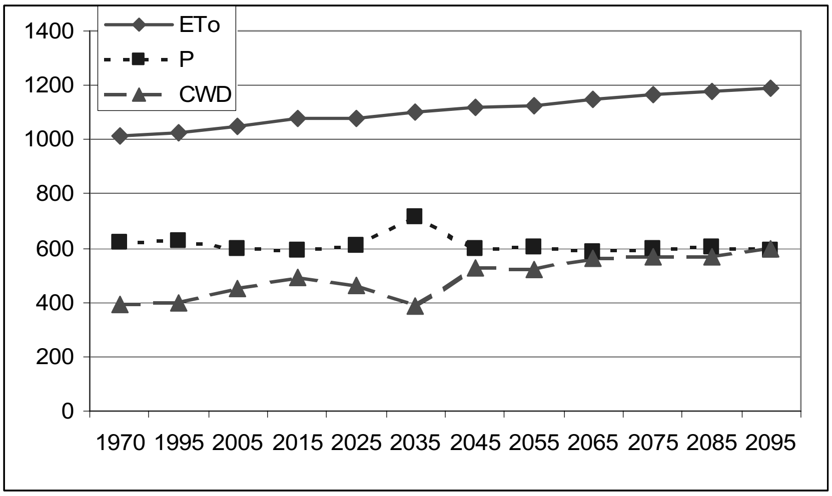


Figure 2. Average annual variation of reference evapotranspiration (ETo), precipitation (P) and climatic water deficit (CWD) in mm/year for the period 1950-2100. The years correspond to the average year of the period under consideration.

An overall increase of temperature, in range between 1.3 and 2°C, is expected in the 21st Century. Accordingly, an increase of ETo of about 15.5% (from 1014 mm/year in the period 1950-1990 to 1190 mm/year in decade 2090-2100) is foreseen over the whole region (Figure 2). A growth of ETo is foreseen for almost all months with the peaks of 25 mm/months observed in June and July (Figure 3).

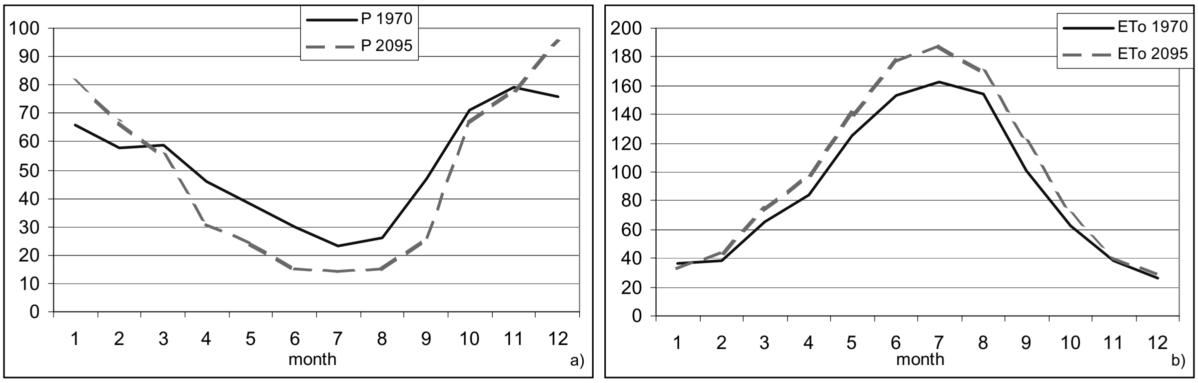
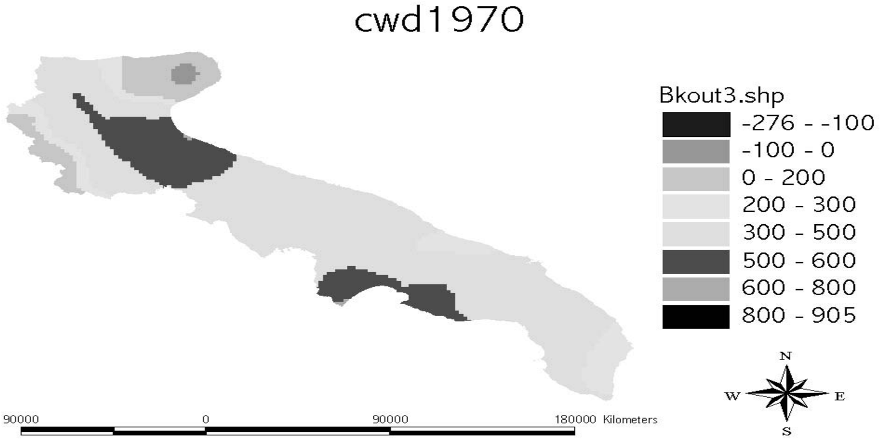


Figure 3. Comparison between the monthly precipitation (a) and reference evapotranspiration (b) data measured in the period 1950-1990 and those projected for the decade 2090-2100.

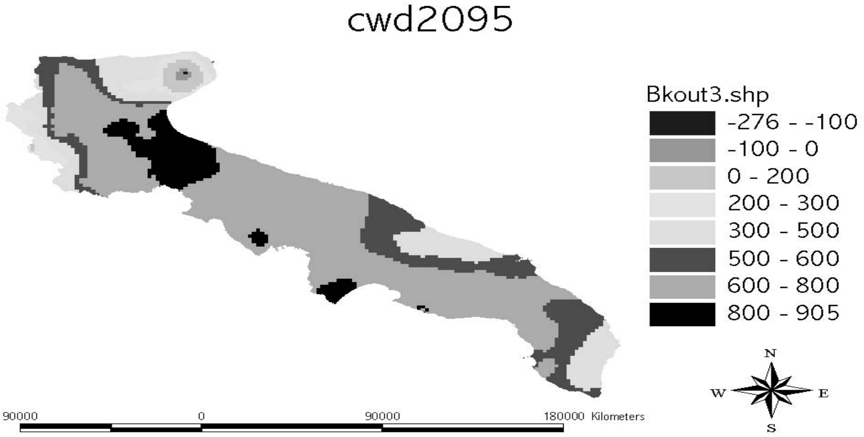
The projections of precipitation data for this century does not reveal significant variations in respect to the period 1950-1990 (Figure 2). An overall slight decrease of about 4.8% (from 622 mm/year in the period 1950-1990 to 592 mm/year in the period 2090-2100) is foreseen on a yearly basis. In particular, a decrease of precipitation (10-15 mm/month on average) is expected for the period between March and October while an increase of more than 20 mm/month is predicted for December and January (Figure 3).

The CWD increase is largely caused by the ETo and in the next 100 years it would increase in average for more than 200 mm (from 392 to 598 mm/year). This trend could be particularly evident for the period 2060-2100 where in the most of the region water deficit is predicted in the range 600-800 mm, while in the last decade (2090-2100) in some areas the CWD would go up to 905 mm. Spatial distribution of CWD over the whole region is given in Figure 4 for the period 1950-1990 and for decade 2090-2100. The greatest increase of CWD (for more than 300 mm in 100 years) is foreseen for the area of Capitanata, located on the North-West of Apulia region and known as one of the most important agricultural zones. Consequently, the future agricultural production in this area will be exposed to serous risks of drought since the Capitanata is already facing a strong water deficit and the irrigation supply has reached the sustainable limits. Moreover, the areas with larger water deficit (more than 600 mm/year) will spread with time from Capitanata in the North towards the Central part of the region and Province of Taranto and the Ionian costs on the South.

In the next 100 years, the areas with CWD in the range 600-800 mm is expected to increase from few percents (about 500 km^2) to more than 50% (about 10,000 km^2). Also, the surface area with water deficit between 300 and 500 mm will drop from 65% (13,500 km^2) actually to 15% (3,000 km^2) by the end of 21st Century. By the same time, it is expected that the area with water deficit greater than 800 mm will cover about 10% of the region.



a)



b)

Figure 4. Climatic water deficit in the Apulia region for the period 1950-1990 (a) and the projected data for the decade 2090-2100 (b).

Actually, water surplus is detected only in the northern part of the Apulia region (Gargano) in some of the decades and it is extended over very limited areas. The projections of climate change indicates that the areas with water surplus will completely disappear by the end of 21st Century.

CONCLUSIONS

The historical weather data confirmed a decrease of precipitations for more than 20% in the Apulia region during the second half of 20th Century. For this Century is expected a moderate increase of temperature and ETo and a slight reduction of precipitation. These results largely coincide with those of some other investigations on climate changes in the Mediterranean region (Pe'er and Uriel, 2000; Ragab and Prudhomme, 2002; DeWrachien et al., 2005). The magnitude of change of weather parameter varies locally and it would have significant influence on the climatic water deficit in the region bringing additional problems related to the water availability and agricultural production.

The on-going trend of variation of climatic variables may increase water demand for different sectors (domestic, agriculture, industry) while keeping the same or even decreasing the volumes of water in accumulations and groundwater aquifers. This would create imbalance between supply and demand side giving the priority of water supply to domestic and industrial sector and limiting water delivery for the agricultural uses. Moreover, higher temperatures may lead not only to the crop water stress but also to the crop heat stress and decrease in crop growth and yield productivity, especially for crops with specific temperature requirements. The increase of air temperature may cause the anticipation of growing season for many crops in the region. However, in some cases, higher temperature may provoke a decrease of growing cycle length and anticipate maturation with consequent yield decrease.

The sustainability of water resource management strategies in the future will be highly influenced by the adaptive responses of each sector and capability to guarantee a more efficient management of water demand. This will be particularly true for agricultural sector that will need to improve not only the efficiency of water storage and delivery systems but also to increase water productivity and to adapt the cropping pattern and management practices to the future climate variability and change.

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Analysis of Effects of Climate Variability on Water Resources of the Suwannee River Basin, Florida

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ABSTRACT

This research aimed to shed light on water availability in the Suwannee River Basin (SRB) in north Florida under various climatic conditions at monthly, seasonal and annual time scales. For this purpose monthly water balances for a period of 30 climatic years (1974/75 – 2003/04) was computed. Water balance is defined as the net change in water over a period of time (ΔS_t) taking into account all the inflows to and outflows from a hydrologic system. This is assumed to be "available water" in the regional hydrologic system. The methodology used distributed data on precipitation, streamflow, evapotranspiration (ET) and consumptive water use (CWU) in a geographic information system (GIS). El Niño Southern Oscillation (ENSO) was used as an indicator of climate variability. Precipitation was significantly affected by ENSO during November and February and during fall and winter seasons. Streamflow was significantly affected during March and April with no effect in seasons. ET and CWU did not show any ENSO related effects. Mean monthly and seasonal water balance was affected by ENSO in the same fashion as precipitation, with water balance affected significantly in the spring season also.

INTRODUCTION

The assessment of water resources of the Suwannee River Basin (SRB) in north Florida is important because water demands within the basin are increasing (Katz and Raabe, 2005). The basin's water availability is highly affected by population and climate variability. The state's natural hydrology systems must meet its water needs for increasing human demands. These systems have specific water requirements in terms of quantity, quality, seasonal variations and geographical locations in the state. The state's abundant precipitation is characterized by spatial and temporal variability, which have significant effects on water availability in various parts of the state at different times of the year. Recently, it has been speculated that north Florida could become a future development hub because of its abundant water resources (Gainesville Sun April 17, 2005). Therefore sustainable planning of water resources in the SRB is required, which calls for information on spatial and temporal variability of inflows and outflows to the basin.

Prior studies on water resources in Florida have primarily focused on individual hydrologic components at a point, usually gauging stations. Schmidt et al (2001) studied spatial variability of seasonal precipitation and streamflow relative to ENSO and reported strong responses that were not uniform across Florida, particularly regarding precipitation in the Panhandle (north Florida) and the southernmost areas of the state. In contrast, Zorn and Waylen (1997) reported that monthly precipitation and streamflow responded homogeneously to ENSO in the southeastern US. Tootle and Piechota (2004) studied streamflow in relation to ENSO for the purpose of predicting long term streamflow in north Florida and the SRB, respectively. Their paper showed a strong ENSO effect on streamflow for the winter and spring seasons. Higher precipitation during El Niño fall and winter and lower values during La Niña and Neutral years in the north Florida region have been reported by Ropelewski and Halpert (1986), Kiladis and Diaz (1989), Schmidt et al. (2001) and Tripathi (2006). Analyses of monthly and seasonal ET relative to ENSO have been limited in north Florida. The Florida Consortium (1999) reported that ET losses were highest in El Niño July compared to La Niña and Neutral years. No seasonal analysis of ET was found.

The above studies do not provide a comprehensive understanding of the water resources in terms of monthly water volumes of each hydrologic component, the resultant water balance at a basin level and their relationship with ENSO phase at various time scales. Such a study is needed for aiding policy makers and water resources planners. The most important issue that led to this research was demand and broadly recognized need for better water resources management in the state and in the SRB (Katz and Raabe, 2005). It was hypothesized that supply and uses of water resources in the SRB are affected by ENSO phases during different times of the year. The objective of this research was to characterize the behaviour of monthly, seasonal, and annual water balances relative to ENSO phases in the SRB.

STUDY AREA

The study area incorporates all of the SRB that falls within Florida, which is 38% of the entire basin and 7% of the landmass in the state. The Florida part of the basin is 10,956 km^2 (Katz and DeHan 1996) and is divided into five watersheds – Alapaha, Withlacoochee, Upper Suwannee, Lower Suwannee and Santa Fe (Figure 1).

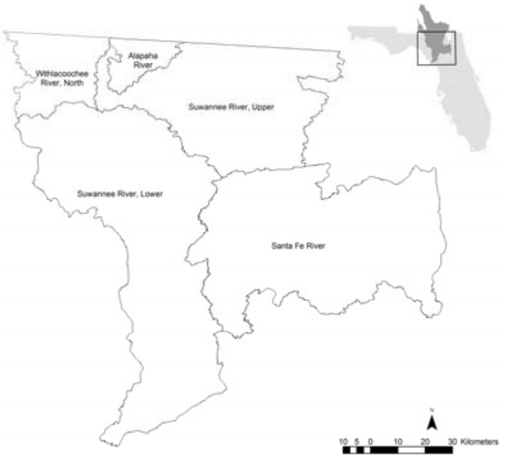

Figure 1: Study area: Suwannee River Basin with major watersheds

The Suwannee River is the most dominant hydrological feature of the basin. The river originates in Georgia and is 435 km long, 383 km of which is in Florida (SRWMD 2000). The river has a mean daily discharge rate of 297 m3 s^{-1} (Raulston et al. 1998) into the Gulf of Mexico. The hydrology of the SRB is driven by climate (SRWMD 2005), which is humid subtropical. Average annual precipitation in the SRB is approximately 135.6 cm (Raulston et al. 1998) and average annual ET estimated for SRWMD was about 99 cm (SRWMD 2005). Historically, the SRB has been largely rural, with little development and low population density. Land use/landcover in the SRB is dominated by subtropical forests, wetlands and agriculture.

DATA AND METHODS FOR ENSO-BASED ANALYSIS

a. Data

The data used in the study were spatially distributed monthly precipitation, streamflow, solar radiation (SRAD), monthly average temperature (T_m) land use/land cover (LULC), and water use and withdrawal (for computing consumptive water use). SRAD, T_m and LULC were used to compute

ET over various landcovers. Volumes of water were computed in units of million gallons per month for each hydrologic component. Accounting for water volumes was based on a spatial water balance modelling approach (SWBMA) developed by Tripathi (2006). The sources of data, detailed steps involving GIS processing and final computation of the water volumes for the hydrologic components can be found in Tripathi (2006). The final (spatial) water balance equation was obtained by incorporating the spatially-computed individual hydrologic components into the classical water balance equation by Thornthwaite (1948) and Mather (1978) based on the conservation of mass theory. The equation was:

$$(\Delta S_t) = (\sum_{i=1}^{n} Pi * Ai) - (\sum_{i=1}^{n} Qi * Ai) - \sum_{l=1}^{7} [Kc_i * (\sum_{i=1}^{n} ET_{pi} * Ai)] - \sum_{c=1}^{m} (\sum_{u=1}^{6} WU * F - A_c * F - CWU_u)$$

where, P_i = precipitation falling on polygon i (m), A_i = area of polygon i (m^2), i = polygons with precipitation, i = 1, n, n = total number of polygons, Q_i = streamflow generated from polygon i (m), ET_{pi} = potential evapotranspiration loss from polygon i (m), K_c = crop coefficient, l = number of LC classes, l = 1, 7, c = counties in a watershed, c= 1, m, m = total number of counties in a watershed, u = USGS individual water use categories, u = 1, 6, $F\text{-}A_c$ = fraction area of the county in a watershed, $F\text{-}CWU_u$ = CWU fraction of individual water use category

b. Methods for ENSO-based analysis

The water balance components were calculated for a period of 30 (1974/75-2003/04) climate years (October 1974 - September 2004) at a monthly time step. They were analyzed for effects of climate variability associated with ENSO phases. An ENSO climate year was defined as one starting in October and ending in September of the following calendar year. This 30-year study includes a number of ENSO phases (‘wet/warm- El Niño: 7 years’, ‘dry/cold- La Niña: 5 years’ and ‘Neutral: 18 years’). The Japan Metrological Agency (JMA) index (COAPS 2006) was used for defining three ENSO phases: El Niño, La Niña and Neutral. Results were analyzed at monthly, seasonal and annual time scales, both without and with respect to ENSO phase. Seasons were defined in this study as: fall (Oct. - Dec.), winter (Jan. – Mar), spring (Apr. – Jun.) and summer (Jul. – Sept.). An analysis of variance (ANOVA) (Steel and Torrie, 1980) was used to test the influences of ENSO phases for each of the hydrologic components and the water balance. A significant response of ENSO on months or seasons was occurred if the ENSO phases differed significantly ($P<0.05$). The Tukey-Kramer honestly significant difference (HSD) test identified which ENSO phases differed significantly in their effects on the hydrologic components or water balance.

RESULTS

a. Precipitation

Based on 30-year averages, July was the rainiest month, whereas November was the driest. Precipitation during El Niño was highest in August and lowest in April and May. In La Niña years, precipitation was highest in September and lowest in November. November and February showed significant responses to ENSO ($P<0.05$). Seasonally, precipitation in the summer was highest and it was lowest in the fall. Precipitation during El Niño was higher than in other phases in all seasons except spring. An ANOVA confirmed significant ($P<0.05$) responses to ENSO for fall and winter precipitation. Annually, in the 30-year study, precipitation was highest in 1990/91 and lowest in 2001/02, both of which were Neutral years. Annual precipitation did not show any distinct trend based on ENSO in the SRB. Compared with Neutral years, precipitation was 7% higher in El Niño and 15% lower in La Niña years.

b. Streamflow

Streamflow was highest in March during El Niño years followed by April and it was least during November. In La Niña years, streamflow was greatest (least) in October (August). Streamflow was considerably higher during El Niño years and lower in La Niña years relative to Neutral years except during October and November when it was higher in La Niña than El Niño and Neutral years. ENSO effects were significant during March ($P<0.05$) and nearly so during April ($P= 0.0574$). Seasonally, streamflow was highest during the winter season and lowest during fall. In El Niño years, streamflow increased from fall (lowest) to winter (highest) before steadily declining in spring and summer. In La Niña, streamflow remained relatively steady but increased slightly in winter (highest) and then declined. ENSO effects on seasonal streamflow were not significant. Annual streamflow did not show any trend with ENSO phase. It was highest and lowest in 1983/84 and 2001/02, respectively, both of which were Neutral years. El Niño produced 17% higher and La Niña produced 13% lower streamflow compared to Neutral years.

c. *Evapotranspiration (ET)*

ET was highest (least) in July (December and January). ET was higher during May through August (highest in July) and lowest from December till February. Over 70% of annual ET occurred between April and September. ENSO did not affect ET significantly. ET was highest (least) in spring (winter) for all ENSO phases (Figure 4-c). In general, ET during El Niño was lower than in La Niña and Neutral years except in the spring season. Annual ET was not significantly affected by ENSO. ET values in El Niño and La Niña years were 2% and 1% lower, respectively, than during Neutral years.

d. *Consumptive water use (CWU)*

CWU did not vary significantly with month or season. During each month and each season, less water was consumed in El Niño and La Niña years than in Neutral years, and CWU in La Niña was less than in El Niño. CWU was not significantly different among the ENSO phases. A possible reason for this lack of differences in CWU among months, seasons or ENSO phases may be the considerably higher values during the 1990 decade than either before or after that time period. The reason for the higher CWU values during this time period are not known, but may be due to one or more of the following reasons:

1. Incomplete data collection in earlier years versus better data reporting in recent times or as a result of population increase in these counties
2. Reporting of water withdrawals from fewer utility companies in the past to more in recent years.
3. Change in water withdrawal data capture and computation methods starting around 1985 (pers. comm., Richard Marella 2006)

e. *Water Balance of the SRB*

Based on the 30-year mean monthly estimates, August had the highest WB value and April and May had the lowest values. WB was higher for El Niño years than Neutral years. In April, May and June, WB in El Niño years was lower than La Niña and Neutral years, which is consistent with lower precipitation and higher streamflows in these months. In both November and February, WB was significantly higher in El Niño than in Neutral or La Niña years ($P< 0.05$). On a seasonal basis, WB peaked in summer and was least (and negative) during spring. During El Niño fall and winter, WB was significantly higher than in La Niña or Neutral years. La Niña years showed lower WB during fall and winter season as compared to El Niño and Neutral years. Winter and spring WB showed significant responses to ENSO phase ($P<0.05$) with La Niña WB significantly less than in El Niño or Neutral years. Effects of ENSO phase during the fall season were weaker ($P=0.069$). Annual WB in El Niño years was higher than during La Niña years. In the 30 years, WB was highest and lowest in 2002/03 (El Niño) and 1988/89 (La Niña), respectively. WB was negative during three of the 30 years (1985/1986-Neutral, 1988/1989-La Niña and 1989/1990-Neutral). In 1985/1986, precipitation was relatively low, ET was high, and streamflow was high. In 1988/1989 and 1989/1990, precipitation was low and ET was high. There were large annual variations in WB between ENSO phases. El Niño produced 9% higher and La Niña produces 58% lower WB, respectively, compared to Neutral years. WB during El Niño years was 61% higher than during La Niña years. Mean El Niño precipitation, streamflow and water balance were higher than in Neutral years whereas ET and CWU were lower. Average La Niña precipitation, streamflow, ET, CWU and WB were all lower than Neutral year values.

DISCUSSION AND CONCLUSIONS

This study analyzed monthly water balance in the SRB region based on ENSO phases. It presented the WB and its hydrologic components at a monthly time step. Annually, 30% (32% in El Niño and 30% in La Niña) of precipitation was converted into streamflow, 52% (47% in El Niño and 60% in La Niña) was lost as ET, 0.5% (0.45% in El Niño and 0.47% in La Niña) was consumptive use and the residual WB of 17% (19% in El Niño and 9% in La Niña) was unaccounted for.

The following overall conclusions were made:

1. Precipitation was higher during El Niño fall, winter and summer compared to La Niña and Neutral year estimates. Higher precipitation in El Niño summers is a new finding.
2. Streamflow values were higher during El Niño winter, spring, and summer. Streamflow values were also higher in La Niña fall.
3. ET losses were highest in July in El Niño years compared to La Niña and Neutral years. On a seasonal scale, ET was highest in El Niño spring and in La Niña and Neutral fall, winter and summer seasons.
4. The WB was higher during El Niño fall, winter and summer seasons, similar to that of precipitation.

In this study, WB for a land area is the residual water from precipitation during a particular time period that is not accounted for by ET, streamflow, or consumptive use losses during that same time period. The length of the time period for the calculation is important in interpreting the WB value. One would expect positive and negative WB values on a monthly time scale due to the transient storage of water in soils, surface water, and groundwater if it is not used by ET or CWU or transported from the area by streamflow.

On an annual basis, one would expect WB to be small if the lags between precipitation and streamflow are on the order of 1 to 3 months. During most years in the study, WB was positive and about 20% of the annual precipitation. Some of this positive WB could be excess water that recharges the aquifer and would thus represent available water. However, this 30-year average water volume residual may also be due to uncertainties in data and calculation of WB. Thus, the WB values do not provide estimates of excess water available for additional uses. The results do provide, however, quantitative estimates of the major components of the WB at the basin scale. Additional research is needed to refine these component estimates for use in water resources management.

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Vulnerability and Adaptation of Wetland's Based Livelihoods in Relation to Climate Variability and Extremes in Simiyu Catchment, Tanzania

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Key words: Climate variability, wetland resources, vulnerability, adaptation

ABSTRACT

This study aimed at identifying hydrological dry and wet years in Simiyu catchment, Southwest of Lake Victoria in Tanzania and assessing community strategies for reducing their impacts. Rainfall anomalies were used to characterise wet and dry seasons between 1950 and 2005. The wet season (October – May) of the hydrological year was divided into three seasons the October-November-December (OND) short rains, intermediate January-February (JF) and March –April–May (MAM) long rains. Field surveys were used to establish the impacts and coping strategies used during the driest and wettest seasons.

The results showed high rainfall fluctuations between seasons and from one year to the other. They further indicated that normally the OND and MAM seasons do not have same strength and sign of anomalies as indicated in 1961/62 and 2005/06 which observed respectively the wettest and driest OND rains. These seasonal fluctuations have led to fluctuations in agricultural, fisheries, and livestock productions. It was further identified that famine was related to erratic OND rains as observed in October 2005 – February 2006. The implications of these erratic and reduced rainfalls are the reduction of river flows and lowering of water levels in wetlands and Lake Victoria. This has led to recently mixed crop farming along the wetlands and lake shores as a coping strategy. The responses of livestock keepers to seasonal severe dryness and wetness include holding vast and varied grazing grounds (transhumance) to have abundant grazing land.

The study has showed that communities living around the Simiyu Catchment are vulnerable to seasonal fluctuations as their socio-economic activities are highly dependent on rainfall. In order for them to have long-term strategies to such variations a clear understanding of the mechanisms that brought such variations and predictions should be established.

INTRODUCTION

Africa is considered more vulnerable to the predicted impacts of climate variability due to, among others factors, its overdependence on all form of natural resources (water, forests, fisheries and agriculture) and limited financial, technological and institutions capacities to respond to predicted impacts of climate change. It is therefore evident that climate change will impact Africa in various ways. The projected impacts of climate change by 2100 in Africa may include increases in temperature of 1.0° to 4.7 °C, reduced rainfall by -2 to –25%, increased evapo-transpiration up to 132% and reduced runoff up to 50% (Magadza, 1996; Hulme, 1996). The implications of such changes on water resources are among the most critical to society and ecosystems since the small amount of water found in the biosphere has a large significance for ecosystems and society (Carpenter, *et al*., 1992). The availability of water influences major biome types and potential agricultural productivity (Carpenter *et al,* 1992). Similarly, human depends directly on freshwater for drinking, irrigation, industries, transportation, recreation and fisheries. Expanding human populations and changes in global climate will exacerbate already severe stress to freshwater resources in Africa (Ausubel, 1991; Chenje and Johnson, 1996; URT, 2003). Sustained variations in global climate can further have enormous effect on distributions and interactions of species (Carpenter *et al.,* 1992).

More than 70% percent of the population in Tanzania is rural and practices subsistence agriculture which is largely rainfed (WHO/UNICEF, 2000). The analysis of current economic and environmental trends in Tanzania reveals an increasing competition over access and uses of freshwater resources including wetlands. Rapid population growth, increasing demand for food, high climate-induced rainfall variability and frequent droughts are putting enormous pressure on wetlands resources. However, there is little information on wetlands responses to climate variability and its implications on rural livelihoods in Tanzania and is often not included in national policies and strategies. Although the National Initial Communication to UNFCC (URT, 2003) included an assessment of impacts of climate variability on countries water resources, the emphasis was on the impacts and not communities responses to such changes. Therefore, information is needed for the purposes of increasing an understanding of the linkage between wetlands ecosystems, climate variability and community's livelihoods which will help in understanding the level of preparedness of communities depending on wetlands ecosystems and their adaptation strategies to impacts of climate variability. This study assessed vulnerability and adaptation of communities living around wetlands at the mouth of River Simiyu discharging into Lake Victoria to document investigated the impacts of variations of hydrological extremes (droughts and floods) on livelihoods of communities depending on wetlands resources.

DATA AND METHODS

Data

Rainfall data for 13 stations within and around the Simiyu catchment were obtained from the Department of Water Resources Engineering of the University of Dar Es Salaam. The rainfall records were of variable quality and length and necessitated the selection of the most suitable records for characterization of drought and flood periods. The selection criteria included minimum record length of 20 years, less than 15% of missing seasonal rainfall and spatial uniform distribution of rainfall stations. These criteria retained six (4) records for analysis.

Primary socio-economic data were collected during field household surveys in three villages of Bubinza, Nsolla and Ilungu surrounding and exploiting wetlands resources. Individual questionnaies, interviesw and focus group discussions were used in the process. A specific time frame which can be remembered by participants was used to investigate climate variability impacts on wetland based livelihoods.

Methods

Seasonal rainfall anomalies were used to characterise years. The year was divided into four known seasons, the short rains (October-December, OND), intermediate January-February (JF) season, the long rains (March-May, MAM) and the dry June-September (JJAS) season. Seasonal rainfall amounts were computed only for seasons with non-missing monthly rainfalls. Seasonal rainfall anomalies were calculated as standardised (division by standard deviation) differences between seasonal rainfall amounts and their long-term averages. That is

$$X_{an,i} = \frac{X_i - \overline{X}}{\sigma_X}$$

(eqn.1)

where X_{ani} is rainfall anomaly in month *i,* X_i is rainfall for month *i*, $\overline{X}$ and σ_X are the long term average and standard deviation of rainfall in month *i*.

The anomalies were used to classify years according to rainfall abundance or deficit. Plots of series of rainfall anomalies were visually analysed to provide limits that appropriately define different levels of wetness and dryness of the year that reflect actual observations. The procedure established five classes (Table 1).

Table 1: Criteria for selection characterization of hydrological years

Criteria	OND	JF	MAM
Extreme wet year	Anomaly > 2.0	Anomaly > 2.0	Anomaly > 1.50
Wet year	2.0 ≥ Anomaly > 1.0	2.0 ≥ Anomaly > 1.0	Anomaly ≥1.00
Normal	1.0 ≥ Anomaly ≥ -1.0	1.0 ≥ Anomaly ≥ -1.0	1.0 ≥ Anomaly ≥ -1.0
Dry year	-2.0 ≥ Anomaly >-1.0	2.0 ≥ Anomaly > 1.0	≤-2.0
Extreme dry year	Anomaly ≤-2.00	Anomaly ≤-2.00	Anomaly ≤-2.5

RESULTS

Identification of wet and dry years

Results are presented and discussed only for the two main rainy seasons (OND and MAM) where agricultural activities are predominant. The time series of OND and MAM anomalies indicated that mostly the two main rainy seasons do not have the same classification as wet or dry in the same hydrological (October – September) year (Table 2). While long rains were extremely abundant in Simiyu only in 1937, the short rains were abundant in 1961 and 1997 (Fig 1). The results further indicated the high reccurrence frequency of dry and wet conditions during the short rains compared to long rains (Table 2). Series of rainfall anomalies further indicated that the extreme driest long rains in Simiyu were experienced in 1973 and 1984 (Fig 1b) correspond to La Niña droughts of 1972-1976 which most parts of northern and northeastern Tanzania (Nyenzi *et al.*, 1999) and wide-spread droughts of 1984 in East Africa (Ogallo and Nasib, 1984).

Table 2: Characterization of Years According to Rainfall Amounts

	Season	
Year classification	Short rains (OND)	Long rains (MAM)
Extreme wet	1961, 1997	1937
Wet	1941, 1951 ,1972, 1982,1994	1981
Dry	1940, 1947 ,1964 ,1966,1970,1993	1933,1953
Extreme dry	1990	1973,1984

Agricultural productions during wet and dry years

Results of field surveys indicated that wet years experienced higher agricultural productions (Table 3) and livestock productions (Table 4) than in normal and dry years. This is attributed by the abundance of water which is available for agricultural activities. In dry years, all the villages experienced low crop productions (Table 3). This was particular during the recent 6 years and was attributed by prolonged hydrometeorological drought that has been experienced in the study area since 2000. This has resulted in the decline of surface water resources including drying up of wetlands and lowering of Lake Victoria levels and consequently reduced water availability for agriculture. Low agricultural productions resulted in low per capita income, since the area depends mainly on agriculture.

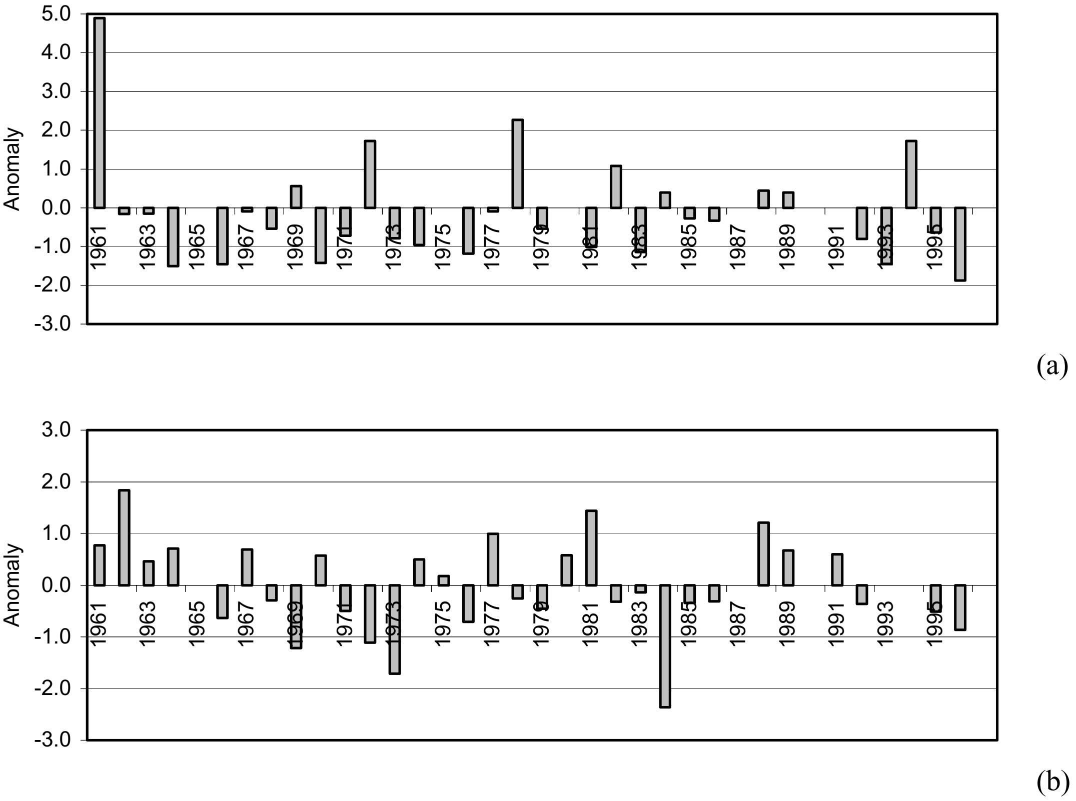

Fig 1: Time series of normalised anomalies of a) OND and b) MAM seasonal rainfall amounts at Ngudu Station (ID 09233005).

Table 3: Crops production and sales (area: acres; production: kg).

Crop	Normal years (eg 2002)		Dry years (eg 2005)		Consumption (kg/mon/hh)	Sale price (TShs/kg)
	Area	Prod	Area	Prod		
Rice	65.25	89,440	45.25	19,840	30	250
Maize	70.50	113,000	62.5	9,285	60	150
Cotton	50.00	44,542	15.00	2,770		300
Cassava	10.50	10,320	6.50	3,420	40	
Water melons	6.25	12,000	6.25	8,500		300
Tomatoes	20.25	224,800	20.25	24,050		100
Sweet potatoes	10.00	360,000	10.00	359		
Dengu	21.00	32,020	11.00	3,640		1000

Table 4: Number of Livestock for Different Years

Name of Village	Dry year (2005)		Normal year (2002)		Difference (Normal-Dry)	
	Cattle	Goat	Cattle	Goat	Cattle	Goat
Nsola	900	102	1049	142	149	40
Ilungu	616	3	913	11	297	8
Bubinza	502	20	786	68	284	48
Total	2018	125	2485	221	730	96

It was identified that the difference for the number of cattle between normal and dry years is not very larger compared to that for goat (Table 4). This was attributed to a higher economic value of cattle than of goats or sheep. This caused greater attention being paid to cattle more than to sheep and goats and consequently cattle receive adequate treatment when suffering from any sort. This lead to their survival compared to sheep and goats and their decrease during the dry years could be resulting from their sell rather than death.

As a coping strategy to frequent droughts in Simiyu, communities are practising shifting agriculture, shifting their farming areas from the uplands into lowlands and drying wetlands. Currently, about 73% of the village population is farming in the wetlands and low land areas due to the prevailing situation of unreliable rainfall and lengthening of dry spells. Despite such efforts, the recent prolonged drought has resulted in low agricultural production. This situation has led to seasonal food shortages of one to six months normally between December and May.

Water supplies during wet and dry years

Communities surrounding Simiyu wetlands obtain water for domestic and agricultural uses from various sources including private piped connections, surface flood water, groundwater (shallow wells and boreholes) and springs. An average daily water consumption of a household is 80 litres from a combination of these sources. However, the major source is groundwater which accounts about 77-89% of the total supply, the lower percentage during the dry years. This indicates the heavily dependence upon a single groundwater source and during drought, when groundwater levels are low, water becomes scarce and people had to walk long distances to collect water. The situation is worse for communities in Nsola and Ilungu villages which rely only on a single borehole which frequently dries during severe droughts leaving only Kisamba spring in Bubinza village, the lake and water vendors as sole sources.

Runoff drainage problems during wet years

Prolonged inundation is a major problem related to runoff drainage in the study area due to the nature of terrain (flood plain). Low-lying plains within and around Simiyu are frequently inundated with flood water and consequently are affected by the effects of prolonged inundation including outbreaks of water borne diseases and loss of residences, properties and infrastructure, crops. This is illustrated during the floods of 1961, 1997 and 2006 when the area was inundated for several weeks. The inundation significantly affected crops, infrastructure and residences and as temporary coping strategy, villagers had to resttle in schools and village stores. Villagers were unable to cultivate the land and consequently productions dropped for some crops like rice, maize, cassava and green vegetables while complete failure of water melons and tomatoes was experienced.

Community vulnerability during wet and dry years

Within the context of climate studies, the most vulnerable are considered to be those who are most exposed to perturbations, have a limited capacity for adaptation and are least resilient to recovery (Bohle *et al* 1994). Based on our wealth ranking (Table 5), results of information analysis indicated that the poor wealth category is vulnerable to impacts of climate variability. Among the contributing factors to such high vulnerability risk are possession of small land and lack of agricultural areas within the wetlands, spending much of their time as labourers as coping mechanism to manage food shortages and spending of their little income on renting small farms in wetlands for potato cultivation.

Among the major coping strategies of the most vulnerable group to droughts are engagement in casual off-farm activities such as water vending, brick making, providing non-motorised transport (bicycle) and trading of firewood and charcoal. In coping with drought conditions, stored dried cassava and potatoes (michembe and udaga) and occasional purchases of cereals are among the major strategies while government assistance is essential in critical conditions.

Table 5: Household wealth status and crop production in the village.

Wealth status	Fraction of population (%)	Crop Production (kg)
Well off	3.9	366,000
Average	49.4	51,920
Poor	46.8	22,160
Total	100.0	440,080

It was further identified that villagers were not planning measures that will reduce the impacts of recurrent floods and droughts. Their only strategy was spiritual on making prayers once they are hit by the event. It was observed that the low level of education and lack of access to basic information like early warning information and weather forecast attributed the situation.

CONCLUSIONS

The study indicated that there are high rainfall fluctuations between seasons and from one year to the other and normally the OND and MAM seasons are not similarly abundant or deficit within the same hydrological year. Their climate-induced variations of the years significantly affect socio-economic activities (mainly rainfed agriculture) and community livelihoods which are mainly dependent on wetlands resources. As a result, community livelihoods are vulnerable to climate variability and its extreme phases that correspond to drought and flood conditions in Simiyu catchment.

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Spatial Variation of Hydrological Floods in Northeast Tanzania

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ABSTRACT

Spatial variation of flooding extreme rainfall and streamflow events in northeast Tanzania occurring during the short rains (October-November-December, OND) was investigated to highlight areas which are mostly affected. Time series of daily rainfall amounts and streamflows during the 92 days of the OND season for the 1950-2004 period were extracted at each station in northeast Tanzania. The wettest periods during the abundant OND rains were identified from the extracted time series and spatial maps established to highlight the onset, advances and retreat of the events.

Results indicated that river flooding during the short rains are frequent in the coastal zone extending between the Indian Ocean and adjacent Usambara Mountains. The severity of these river floods were spatially and temporaly variable with the most severe floods occurring in 1982 and 1997 in the coastal zone, 1978 in central inland zone and 1961 and 1997 in the upper high mountains zone. Results further indicated that flooding rainfall events during the short rains are infrequent, short-lived and usually occur during the El Niño events. Daily rainfall amounts exceeding the 95% percentiles (which are 30 - 45 mm) more often occur across the whole northeast Tanzania and do not necessarily result in river flooding. However, floods are mostly caused by amounts exceeding 50 mm which are infrequent and usually observed in the coastal zone where altitude and local sea surface temperatures significantly affect rainfall amounts.

These results indicates the importance of local waters and altitude in the occurrence of hydrological extremes in northeast Tanzania. They indicate the localised nature of floods in northeast Tanzania contradicting the commonly perception of “flooding in East Africa” that is related to regional floods rather than localised floods. The results could beneficially be utilised to reduce the impacts of climate-induced hydrological extremes on water resources management, socio-economic activities and transportation infrastructure.

INTRODUCTION

Several recent studies (Valimba, 2005; Valimba *et al*., 2005) and actual observations have indicated significant changes in the rainy seasons characteristics (onsets and ends, total amounts, intensities, raindays frequency, dry spells, etc). Valimba (2007) further indicated the varying distribution of rainfall events and number of raindays in different short rains with heaviest rainfalls during the 1982 short rains received between 14th November and 2nd December. The recent work of Valimba and Mkhandi (2005) indicated the role of surrounding Indian Ocean waters on the occurrence of intense daily rainfall amounts in coastal areas of northeast Tanzania. However, the large-scale influences of ENSO, Atlantic and Indian Oceans were identified to influence the occurrences of short rains in the country (Indeje *et al*., 2000) particularly ligth and moderate rainfall amounts (Valimba, 2005). The increase of the frequency of intense rainfall amounts related to changes of influencing climatic variables (Trenberth, 1990, Kerr, 1992, Wang, 1995, Trenberth and Hoar, 1996, Trzaska et al., 1996, IPCC, 2001) and depletion of perennial forest cover are contributing to increasing occurrence frequency and severity of floods in the country. Observations and reports have indicated that floods are often experienced in eastern and northern parts of the country. Consequently, greater damages have been reported in regions like Tanga, Kilimanjaro, Mwanza and Shinyanga (FEWS, 1998).

Appropriate management of water resources, provision of adequate defense against devastating floods and improving the availability of water to communities requires i) better understanding of the spatial extent of hydrological extremes to delineate areas that are mostly affected and ii) proper prediction of the timing and behaviour of hydrological extremes at relatively long lead times. This will allow for appropriate measures to be taken to safeguard people and property against floods and droughts. Forecasting models for these hydrological extremes are therefore necessary. Unfortunately, this area of prediction of hydrological extremes has received less attention despite its known negative impacts on socio-economic development. Therefore, this study therefore attempts to highlight the spatial extent of river flooding that occurs in northeast Tanzania during the short rains and its association with rainfall.

DATA AND METHODS

Data

Daily streamflow records at 29 flow gauging stations in northeast Tanzania were obtained from the Hydrology Section of the Ministry of Water, the Department of Water Resources Engineering of the University of Dar es Salaam and Regional Hydrologists of Kilimanjaro and Tanga. Rainfall records for 112 stations were obtained from the Department of Water Resources Engineering of the University of Dar es Salaam, Ministry of Water and the Tanzania Meteorological Agency.

Most of the streamflow and rainfall records were short spanning mainly the 1960s through the 1980s and have varying percentages of missing daily observations. Only six streamflow records start in the 1950s and only two have data through the 2000s. The variable record characteristics (length, period of availability, missing observations, etc) necessitated selection of suitable records. Since the study investigates hydrological floods during the short rains (1st October – 31st December, OND), 16 flow (Table 1) and 55 rainfall (Fig 1) stations with most continuous daily records for at least 15 years during the OND season were retained. Annual series (1st October – 30th September) were used to define flooding flows.

Table 1: Inventory of streamflow records and availability of daily data.

Sno.	Code	River	Location	Lat	Long	Area (Sq km)	Available record
1	1B1B	Umba	D/S Kitivo Weir	-4.5167	38.3833	258	Aug 1970-Dec 1992
2	1B4A	Umba	Mwakijembe D/S	-4.5139	38.8917	7130	Feb 1963-May 1995
3	1C1	Sigi	Lanconi Estate	-5.0139	38.7997	705	May 1957-June 1990
4	1DA1A	Luengera	Korogwe	-5.1333	38.5750	800	Aug 1953-Feb 1995
5	1DA3A	Luengera	Maji Rest Hse.	-4.8722	38.5667	28.5	Mar 1967-Dec 1990
6	1DB2A	Seseni	Gulutu	-4.4639	38.0611	166	May 1963-Feb 1984
7	1DB17	Mkomazi	Gomba	-5.0222	38.2792	3341	Jan 1962-Dec 1995
8	1DB18	Hingilili	Kiruka	-4.2347	37.9736	38	Jan 1963-Dec 1995
9	1DB19	Soni	Soni	-4.8375	38.3708	330	Jan 1976-May 1994
10	1DB22	Mkusu	Kibohero	-4.7292	38.2861	25	May 1975-Dec 1987
11	1DC2A	Ruvu	Tanga Rd.Brg.	-3.5250	37.4667	3368	Jul 1952-Dec 1991
12	1DC6	Mue	Kahe/Taveta Br.	-3.8833	37.4667	164	Aug 1952-Dec 1987
13	1DC11	A Himo	Moshi/Tanga Br.	-3.5000	37.5333	264	Nov 1952-Dec 1985
14	1DD1	Kikuletwa	Blw Weruweru co	-3.5167	37.2833	2849	May 1952-Feb 2005
15	1DD6A	Weruweru	Forest Boundary	-3.1500	37.2667	68	Feb 1969-Jul 1987
16	1DD54	Kikuletwa	Tanesco P.House	-3.4583	37.2917	2220	Feb 1967-Mar 2005

Methods

Flow duration curves (FDCs) constructed from annual series were used to define index flood flows that appropriately reflect flood observations irrespective of the season. The higher Q1 and Q2 flows are observed in very few years (2 – 4 years) with severe river flooding and do not provide sufficient information regarding the frequency of flooding. Q5 flows generally provide the required information and were adopted as flood flow index. Years which observed flows above this threshold during the short rains were identified at each gauging station. The spatial analysis of the influence of rainfall on river flooding was investigated by plotting the maps of the events for the period comprising the flooding event and seven days before and after the event.

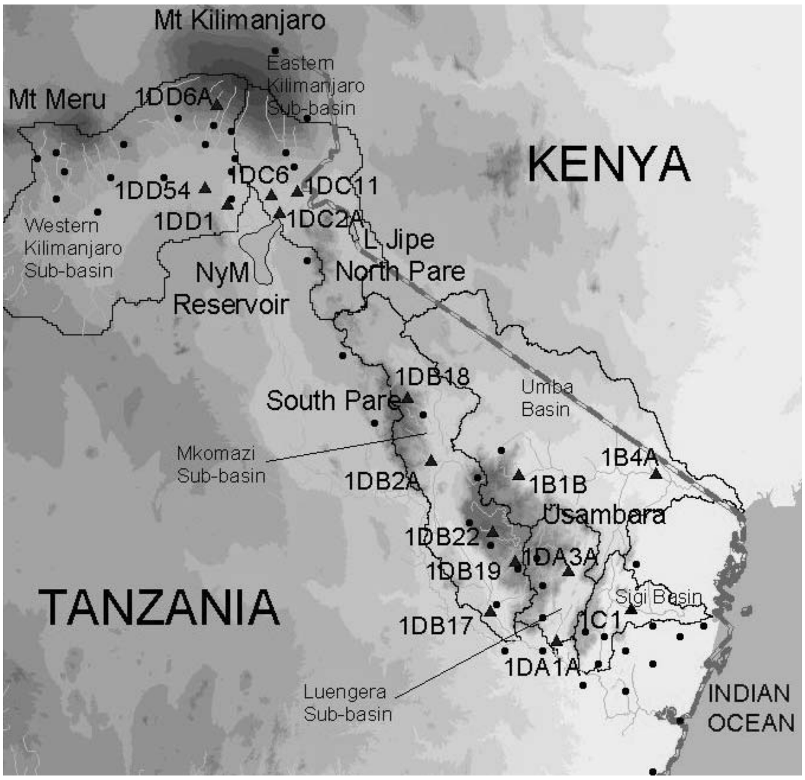

Fig 1: Spatial distribution of selected rainfall (dots) and streamflow (triangles) station for analysis.

RESULTS AND DISCUSSION

River flooding during the short rains in northeast Tanzania

Results indicated that river floods in northeast Tanzania that occur during the short rains are spatially non uniform across the whole region and their severity varies between the years (Table 2). The floods of 1961 were severe in the inland northern part, those of 1978 were severe in the inland central parts while the 1982 floods were particularly severe in the coastal zone. Depending on the causal climatic conditions, floods during the short rains may or may not occur everywhere in northeast Tanzania. Although the intensity of the 1982 El Niño floods was spatially variable, the floods were observed across the region. However, those in 1977 and 1978 were observed in the central and coastal zones (Table 2).

The probable influence of rainfall

The results indicate that extreme river floods in northeast Tanzania were experienced mainly in 1961, 1978, 1982 and 1997. Despite flow data for 1997 being available at only two stations, visual observations and field reports during this El Niño flood event have indicated flooding of varying levels of severity in most parts of northeast Tanzania. Periods which observed highest flows during the three OND months of the short rains in each of the four years were identified (Table 3). It was observed that the persistency of flooding events was spatially and temporally variable and was affected by rainfall intensities and persistency. The continuous moderate rainfalls during the 1961 "Uhuru" short rains (Fig 2a) resulted in persistent river flooding in northeast Tanzania (Table 3) as reported in other parts of the country (Tumbo, 2007). However, isolated intense rainfalls during the 1982 (Fig 2b) and 1997 El Niño events, in which daily amounts exceeding 100 mm and reaching above 300 mm can be received (Fig 3), were responsible for less persistent river flooding in the region (Table 3).

Table 2: Flooding years in rivers in northeast Tanzania. ENSO years are shown in red while the years experienced the most severe floods are bolded.

Code	Available records	Flooding years
1C1	May 1957-Jun 1990	1961; 1965;1967;**1968**;1972;1977;1978;1980; **1982**; 1984
1DA1A	Aug 1953-Feb 1995	1961; 1967; 1972;1977; 1981;**1982**
1DA3A	Mar 1967-Dec 1990	1967;1968;1972;1977; 1981;**1982**
1DB2A	May 1963-Feb 1984	1963;1965; 1968; 1977;**1978**;1980;1981;1982
1DB17	Jan 1962-Dec 1995	1967; 1977;**1978**
1DB18	Jan 1963-Dec 1995	1963; 1968;1972;1977;**1978**; 1983
1DB19	Jan 1976-May 1994	**1978**; 1982; 1989
1DB22	May 1975-Dec 1987	1982
1DC2A	Jul 1952-Dec 1991	**1961**;1963; 1968;1973; 1982
1DC6	Aug 1952-Dec 1987	**1961**; 1974; 1987
1DC11	Jan 1969-Dec 1985	1972; 1982
1DD1	May 1952-Feb 2005	**1961**; 1968; 1982; 1997
1DD6A	Feb 1969-Jul 1987	1972;1977;1978; **1982**
1DD54	Feb 1967-Mar 2005	1968; 1982; **1990**;1997

Table 3: Persistency of river flooding during the short rains in northeast Tanzania.

Code	Severe flooding events
1C1	**1961:** 20th Oct –7th Nov; **1978:** 4th Dec – 9th Dec; **1982:** 10th Oct – 26th Oct, 16th Nov – 22nd Nov, 29th Nov – 8th Dec; **1997:** No data
1DA1A	**1961:** 8th Nov – 15th Nov; **1978:** 29th Nov – 30th Nov; **1982:** 12th Oct – 2nd Nov, 21st Nov – 23rd Nov, 29th Nov – 18th Dec; **1997:** No data
1DA3A	**1961:** No data; **1978:** No flooding; **1982:** 8th Oct – 5th Nov, 15th Nov – 24th Nov, 27th Nov – 23rd Dec; **1997:** No data
1DB2A	**1961:** No data; **1978:** 12th Nov – 15th Nov, 1st Dec – 30th Dec; **1982:** 27th Nov – 8th Dec; **1997:** No data
1DB17	**1961:** No data; **1978:** 8th Dec – 31st Dec; **1982:** No flooding; **1997:** No data
1DB18	**1961:** No data; **1978:** 16th Nov – 31st Dec; **1982:** No flooding; **1997:** No data
1DB19	**1961:** No data; **1978:** 30th Nov – 19th Dec; **1982:** 30th Nov – 31th Dec; **1997:** No data
1DB22	**1961:** No data; **1978:** No flooding; **1982:** 28th Nov – 2nd Dec; **1997:** No data
1DC2A	**1961:** 11th Nov – 8th Dec, 13th Dec – 31st Dec; **1978:** No flooding; **1982:** 3rd Dec – 16th Dec; **1997:** No data
1DC6	**1961:** 7th Dec – 24th Dec; **1978:** No flooding; **1982:** No flooding; **1997:** No data
1DC11	**1961:** No data; **1978:** No flooding; **1982:** 1st Dec – 4th Dec; **1997:** No data
1DD1	**1961:** 6th Nov – 7th Dec, 12th Dec 17th Dec; **1978:** No flooding; **1982:** 30th Nov – 5th Dec; **1997:** 5th Nov, 8th Nov
1DD6A	**1961:** No data; **1978:** No flooding; **1982:** 7th Oct – 15th Oct, 21st Oct – 24th Oct; **1997:** No data
1DD54	**1961:** No data; **1978:** No flooding; **1982:** 28th Nov – 2nd Dec; **1997:** 6th Dec – 9th Dec

CONCLUSIONS

The study has indicated the spatial localised nature of river flooding in northeast Tanzania in which different areas of the region has experienced flooding events in different years. The severe and less persistent flooding events were more frequent in the coastal zone where extreme intense rainfalls do often occur as observed during the 1982 and 1997 El Niño influenced short rains than in other parts of northeast Tanzania. Continuous moderate and moderately heavy rainfalls as observed during the 1961 short rains were mostly responsible for persistent river flooding in the region. The study suggests the need to incorporate the spatial variation of river flooding and flooding rainfalls in socio-economic and infrastructural planning and designs to minimise costs related to flood management.

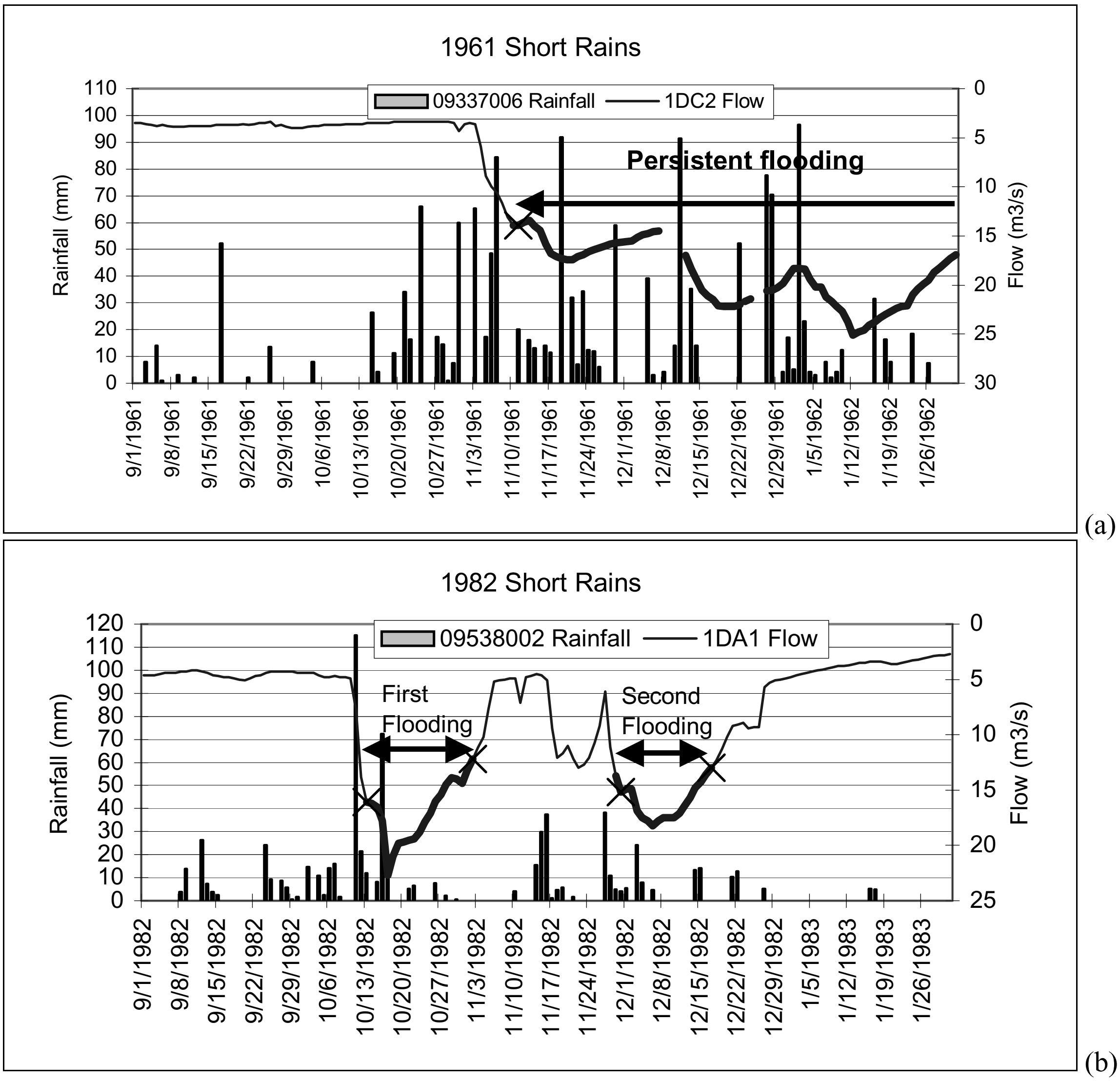

Fig 2: Relating river flooding to intense and prolonged rainfalls: a) 1961 floods at 1DC2 (inland northern zone) and b) 1982 floods at 1DA1 (Coastal zone).

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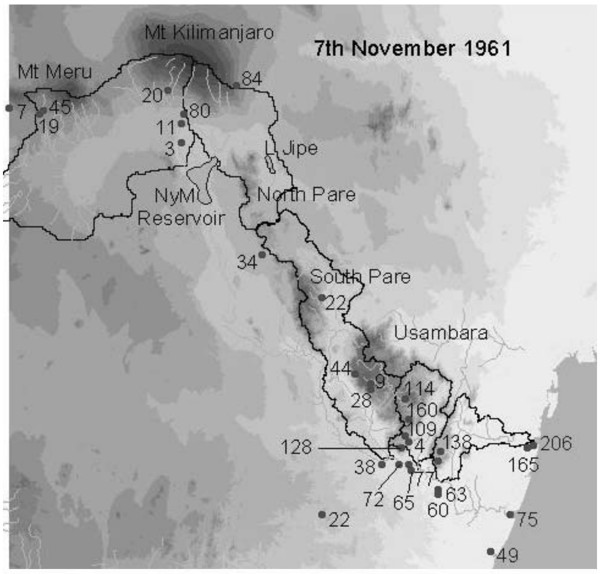

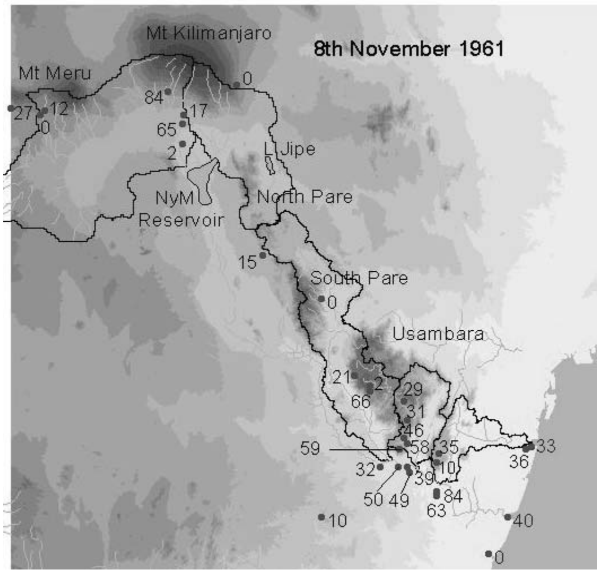

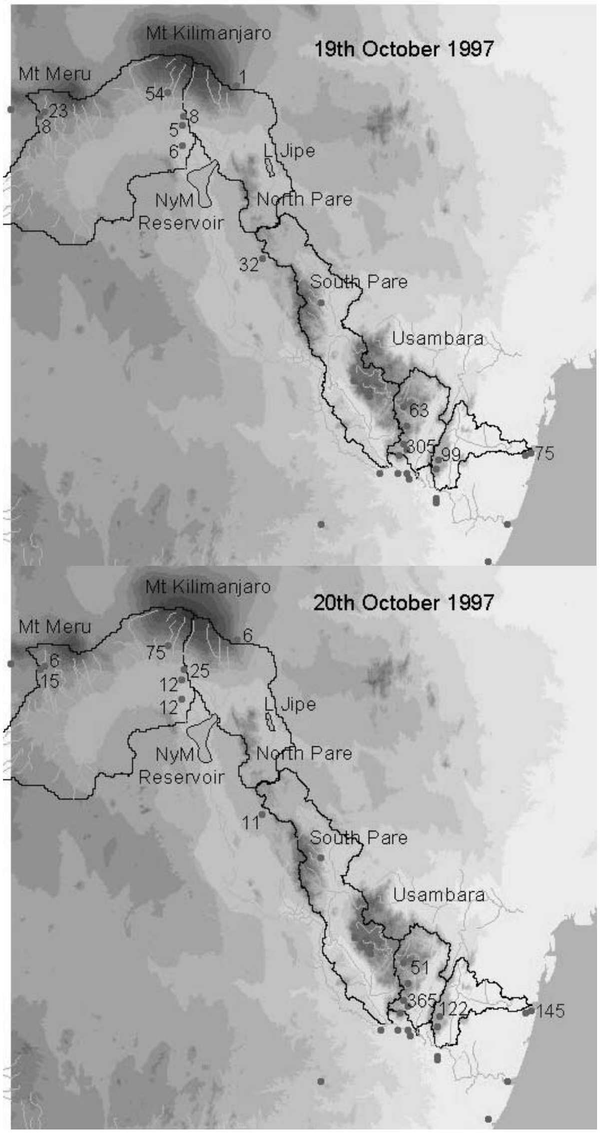

Fig 3: Spatial distribution of daily rainfall amounts (mm) on 7th and 8th November 1961 (Top panels) and 19th and 20th October 1997 (Bottom panels) during flooding events in northeast Tanzania.

Hydrological drought, climate variability and change

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Keywords: groundwater, streamflow, drought, hydroclimatology, climate change, WATCH

ABSTRACT

Time series of observed meteorological data were retrieved from the CRU TS 2.10 dataset and next groundwater recharge and discharge (1970-2002) were simulated with hydrological models for a humid continental climate (Missouri, USA) and a tropical savanne climate (Guinea). Recharge was simulated for two soil types and groundwater discharge for quickly and slowly-responding catchments. Eight time series were analysed to investigate droughts in precipitation, recharge and groundwater discharge. The study shows that climate and the responsiveness of the catchment (e.g. aquifer characteristics) have a major influence on drought generation. The natural variability in the climate system will cause the drought to occur irregular in time (both short and long term), whereas a strong seasonality will govern the annual cycle. In addition, different hydrological processes and the physical structure of the catchment will lead to different responses in the hydrological system. The paper concludes with the role of the EC-IP WATCH project in upcoming drought research. This project will investigate the space-time development of droughts in the 20th century including possible causes for observed trends/changes (attribution) as well as droughts in the 21st century including an assessment of the sensitivity in the droughts due to climate change and other anthropogenic influences.

INTRODUCTION

Drought is one of the most severe climate-driven natural hazards. It is defined as a sustained and regionally extensive occurrence of below average natural water availability, and can thus be characterized as a deviation from normal conditions (Tallaksen & van Lanen, 2004). It occurs in all hydroclimatological regions, although frequency and severity vary. Droughts should not be confused by aridity, which is a permanently low water availability (potential evaporation significantly larger than precipitation) or water scarcity, which reflects an imbalance between water demand and availability. Droughts start with a precipitation deficit over a large area and for an extensive period of time (meteorological drought). The deficit propagates through the terrestrial part of the hydrological cycle and may cause a hydrological drought to develop (groundwater and streamflow droughts). A thorough understanding of drought generation in different hydroclimatological regions is required for drought forecasting, which is essential for adequate management of both groundwater and surface water resources. Moreover such knowledge is vital for the prediction of the likely impact of climate change on drought. Recent leading reports suggest an enhancement of the global water cycle implying an increase of frequency and severity of droughts (IPCC, 2007a; 2007b).
The main objective of this paper is to evaluate the significance of hydrological processes and the physical structure of the catchment (i.e. subsurface water flow and storage) for the development of hydrological droughts in contrasting hydroclimatological regions. It concludes with some remarks on future challenges in drought research. Special attention is given to the EU supported WATCH (Water and Global Change) project, which investigates drought generation at different scales (river basin to global) and in a wide range of hydroclimatological regions for both the past and future climate.

HYDROLOGICAL DROUGHT AND CLIMATE VARIABILITY

Data and Methods

Time series of monthly meteorological data (period 1970-2002) were retrieved from the CRU TS 2.10 dataset (Mitchell & Jones, 2005). Potential evapotranspiration was calculated according Thornthwaite-Malton (Dingman, 2002). Two 1^o x 1^o regions (consisting of four 0.5^o x 0.5^o cells) with contrasting climates were selected, i.e. Missouri (USA), 38-39^0N, 92-93^oW, and Guinea, 11-12^0N, 11-12^oE. The region in Missouri has a humid continental climate with a warm summer (Köppen: Daf). The average monthly temperature varies from around 0°C in January to about 25°C in July, and the average precipitation is lowest in winter (42 mm in January) and highest in May (123 mm). Total average annual precipitation is 1010 mm. The region in Guinea has a tropical savanne climate (Köppen: Aw) with a rather constant temperature over the year (25-30^oC). The region has a clear wet season, with monthly precipitation over 100 mm in the period May-October. It hardly rains in the period December-March. The average annual precipitation is 1340 mm. A soil-water balance model that uses precipitation, potential evapotranspiration and soil data as input data, was applied to simulate time series of monthly groundwater recharge (van Lanen *et al.*, 1996). This has been done for two different soil types (Table 1). Soil type A is less susceptible to drought than B due to its higher storage capacity and, consequently, has a higher actual evapotranspiration. The computed average annual groundwater recharge for soil types A and B is 213 and 277 mm in Missouri and 447 and 520 mm in Guinea, respectively.

Table 1. Soil data

Soil type	Rootable depth, m	Moisture content, vol. %			Soil moisture storage, mm			Available soil moisture, mm	
		FC[1)]	CP	WP	FC	CP	WP	total	readily
A	0.5	30	8	4	150	40	20	130	110
B	0.5	41	36	25	205	180	125	80	25

[1)] FC: field capacity, CP: critical point, and WP: wilting point.

A simple groundwater model that is based upon linear reservoir theory (Tallaksen & van Lanen, 2004) has been applied to simulate time series of groundwater discharge for the two soil types in Missouri and Guinea. The groundwater body is characterized by the transmissivity and storativity of the aquifer and the distance between the streams. Two different groundwater bodies were defined: (1) quickly-responding catchment and (2): slowly-responding catchment. The quickly-responding catchment has small distances between streams and high transmissivities and storativities, the slowly-responding catchment has opposite characteristics. In this study, the quickly and slowly-responding catchments have a reservoir coefficient *j* of 100 and 2500 days (e.g. Tallaksen & van Lanen, 2004), respectively. The simulated time series of groundwater recharge were fed into the hydrological model.

Drought characteristics (i.e. onset, duration, severity) were derived from the simulated time series by using the threshold level approach (Yevjevich, 1967). Threshold levels for precipitation, recharge and groundwater discharge (*P70*, *R70* and *Q70)* were derived, equivalent to the value that is equalled or exceeded in 70% of the time. Two different types of threshold levels were applied. The constant threshold level is derived based on data for the whole year and not a specific period and only one value results. The varying threshold level approach uses a seasonal or monthly-varying threshold level. In the latter case a drought can be defined rather as an anomaly of the time series (Hisdal *et al.*, 2004). The monthly-varying threshold level is calculated based on data only for the particular month, resulting in 12 different threshold levels. A given month is experiencing drought if the variable of interest in a particular month is smaller than the monthly threshold level. The monthly-varying threshold level has been introduced to cope with a marked seasonality and is eventually chosen for this study.

RESULTS

In Guinea all droughts in precipitation occur in the period October-March when a constant threshold was used (not shown). About 50% of the droughts that last 3-5 months end in the period March-May. Clearly, the strong seasonality in precipitation leads to this result. For groundwater and streamflow, however, the deviation from normal in the wet season, rather than in the dry season, is dominating,. Hence, the use of monthly-varying threshold level is more appropriate for this region. This is supported by the analysis of the monthly recharge, which also has a clear seasonality for both regions. In Missouri over 80% of the recharge happens in the period November-May (Soil B), and in Guinea even 90% occurs in July-September. The strong seasonality in the recharge in Guinea also causes a

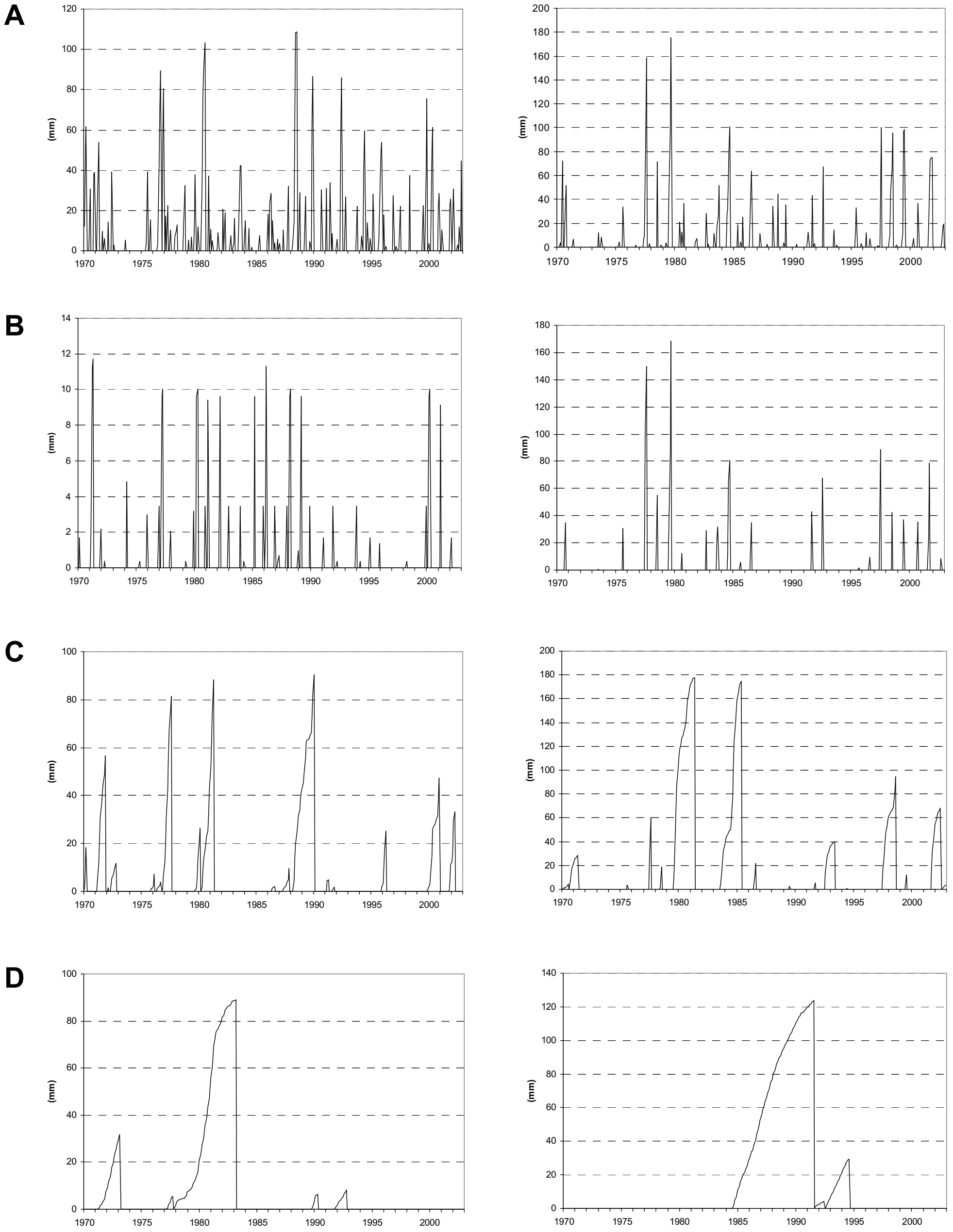

Figure 1. Drought severity (expressed as accumulated deficit) based upon monthly-varying threshold levels. Left panel: Missouri, and right panel: Guinea. A: precipitation anomaly, B: recharge

anomaly (soil B), C: discharge anomaly for a quickly-responding catchment (Soil B), and D: discharge anomaly for a slowly-responding catchment (Soil B).

rather dynamic groundwater discharge even for slowly-responding catchments (not shown). In the following only the results for the variable threshold level are presented. Figure 1 gives the severity of the drought in precipitation, recharge (Soil B) and groundwater discharge for quickly and slowly responding catchments in Missouri and Guinea, respectively. In Missouri more (82 events), but smaller deficits in precipitation (max. 109 mm) have been identified (Fig. 1A) than in Guinea (62 events; max. 175 mm). In Missouri seven events last more than two months, of which five events occur before 1983. In Guinea, eight of such longer lasting events occur that are unequally distributed over time; they seem to cluster around 1979, 1985 and 2000. Fewer droughts in recharge have been detected, i.e. 42 for Missouri and 23 for Guinea (Fig. 1B) than in precipitation, which is can be expected due to the soil moisture store. The occurrence of droughts in recharge also varies over time. The outcome of the recharge analysis has been affected by the many monthly *R70* values that are zero (67% for Missouri and 75% for Guinea), implying that in these months no recharge drought can occur. In groundwater discharge only a limited number of droughts were identified, which applies both to the quickly-responding (Fig. 1C) and the slowly-responding catchments (Fig. 1D). This in line with earlier conclusions (e.g. Peters *et al.*, 2003; Tallaksen & van Lanen, 2004). For example, in a slowly-responding catchment in Missouri and Guinea only 5 respectively 3 major droughts occur. Meteorological droughts happen more often (Fig. 1A) and last shorter (Tallaksen *et al.*, 2006) than the hydrological droughts (Figs. 1C and 1D). Comparison of the results for Soils A and B shows that the different groundwater recharge affects the drought in groundwater discharge. However, the differences are rather small compared to the differences between the selected quickly and slowly-responding catchments. The droughts in groundwater discharge clearly show an unequal distribution over time as a result of natural climate variability.

HYDROLOGICAL DROUGHT, CLIMATE VARIABILITY AND CHANGE: AN OUTLOOK

It is hard to distinguish between effects of climate change on drought and multi-decadal climate variability, as presented in the previous section. Furthermore, it is difficult to discriminate from other human influences (e.g. land use change, water abstractions). Different approaches have been followed to assess the impact of climate change on drought. Commonly, physically-based, process-oriented models are applied in combination with observed time series of hydrometerological data. Pan-European (e.g. Hisdal *et al.*, 2001; Pekarova *et al.*, 2006) and comprehensive national studies (e.g. Lang *et al.*, 2006; Marsh *et al.*, 2007) show that no significant changes in streamflow were found for most stations, however, distinct regional differences for hydrological drought conditions in Europe occur.

EC-IP WATCH

Hydrological observations show that our understanding of the global water cycle, including the development of past droughts and how they might change in future is very fragmented and highly uncertain. The current generation of global and regional climate models (GCMs and RCMs) is still expected to unsatisfactory reproduce historical extremes, given the considerable variability in the prediction of rainfall patterns, including differences between climate models and between different ensemble members of the same climate model. There are many sources of information, which have a wide range of space and time scales and also originate from different scientific communities (e.g. climate, hydrology). The EC Integrated Project (WATCH: WATer and climate CHange) will advance the knowledge and skills to predict the effect of climate change on drought by enhancing our understanding of the present situation. It will analyse and describe the current global water cycle (20th century), especially causal chains in the physical system (climate-hydrology) leading to observable changes in extremes (e.g. droughts). It will evaluate how the global water cycle and in particular droughts (21st century) respond to future drivers of global change. WATCH will assess the uncertainties in the predictions of climate-hydrological-water resources model chains using a combination of model ensembles and observations. WATCH will also investigate the attribution of changes in the hydrological cycle (incl. the extremes), discriminating between external drivers, both natural and anthropogenic, and internal variability. In terms of hydrological extremes (drought and flood), the frequency, severity and scale of the events will be analysed, with emphasis on past and future conditions. It will address possible causes for observed trends/changes in the extremes (detection and attribution) and evaluate the sensitivity in the extremes due to climate change and other anthropogenic influences. Different climatological and hydrological models and combinations will be used to detect droughts (Fig. 2).

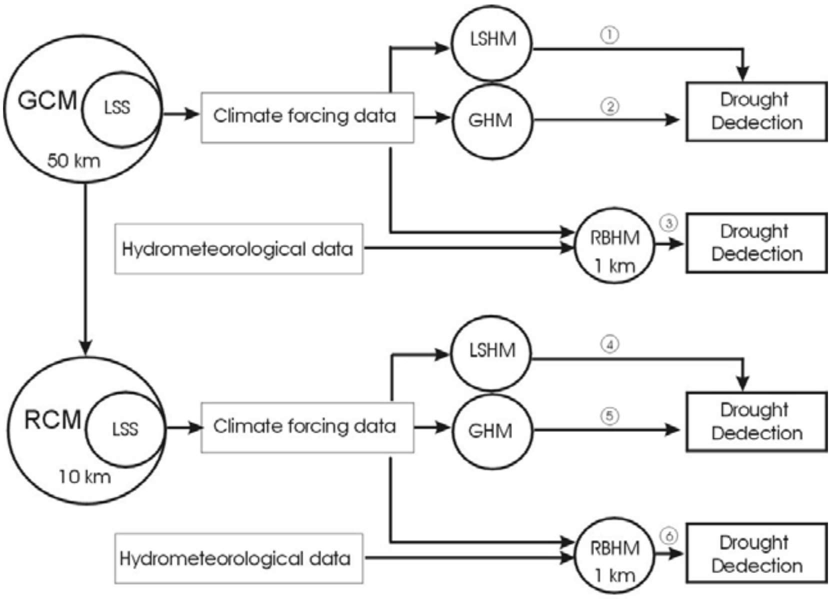

Figure 2. Flow chart showing how droughts are derived by using different models in the framework of the WATCH project (LSS: Land Surface Scheme, LSHM: Land Surface Hydrological Model, GHM: Global Hydrological Model, and RBHM: River Basin Hydrological Model).

WATCH has, however, focus on climate change and large scale modelling, and knowledge on the physical system (climate and hydrology) still needs to be enhanced, particular covering the wide range of hydroclimatological regions across the world. This includes a better understanding of driving forces in the climate system leading up to drought and the development (space-time) of a meteorological drought into a soil water and hydrological drought. Improved knowledge in these fields is essential for early warning systems as well as for the prediction of possible impacts of climate change.

CONCLUDING REMARKS

Climate variability has a major impact on drought development. Large differences in hydrological drought generation (streamflow and groundwater) are found between regions with different hydroclimatology as illustrated here for catchments in Missouri and Guinea, which confirms earlier studies (e.g. Tallaksen & van Lanen, 2004; van Lanen, 2006). In addition to climate forcing that controls variability of meteorological drought, the physical responsiveness of the catchment (quickly versus slowly) to recharge has a major influence on the propagation of drought through the hydrological cycle and thereby affecting variability of hydrological drought.

Despite the very convincing evidence on global warming (IPCC, 2007a; 2007b), it is still hard to detect changes in hydrological drought in the 20th century and, if occurring, to attribute to climate change. Most studies do not show clear trends in time and over extended areas. It is anticipated that the EC-IP WATCH will advance our knowledge on drought generation in different hydroclimatological regions for different physical catchment structures also considering climate change.

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Impact of Climate Change on high and low discharge on Flemish rivers

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Keywords: hydrological extremes, composite hydrographs, climate scenarios, Flanders, Dender catchment

ABSTRACT

In climate change studies, the influence on hydrological extremes is much more uncertain than temperature evolution, having serious consequences for risk management in river catchments. Flanders Hydraulics Research (Department of the Flemish Administration, Ministry of Mobility and Public Works) set up a study program, executed by the Hydraulics Department of Leuven University together with the Royal Meteorological Institute of Belgium and consultant IMDC. They selected a set of climate change scenarios for Flanders.

The Dender River is chosen as a pilot case to research the influence of changing rainfall and evaporation patterns on river discharges. A serious decrease of summer rainfall together with an increase of evaporation result in more extreme low flow discharges. The summer base flow can decrease with more than 50% during dry summers. This increases the chance on water deficits, with adverse consequences for drinking-water production, shipping, agriculture, industry, nature …
Although frequently associated with climate change, the increase of flood probabilities is not that clear in the results. Peak discharges in a river like the Dender do not rise more than 15% in the most extreme scenarios while their mean trend is even diminishing a few percents.
The uncertainties remain high for secondary effects of climate change like flooding. Therefore climate evolutions have to be monitored and analysed very intensively during the next decades. New water policy projects must incorporate possibilities for adaptive measurements. Especially the problems of water availability during summer need further analysis and follow-up.

INTRODUCTION

At present policy makers accept that the probability of flooding can never be zero. Along waterways, organizations and individuals take measures to lower the probability and / or the consequences of flooding to come to “an acceptable risk”. Besides the question “What is an acceptable risk?” – which will not be discussed in detail in this paper – there is the question “What’s the future risk?” Many measures taken now are planned to be effective for a number of years. Soft measures can be adapted after a few years but new dykes, controlled inundation areas, reduced tidal areas, and storm barriers are not easy to change or re-dimension. They are planned to be effective for 50 years or even longer. So having an idea about the possible hydraulic extremes and land use evolutions in the future is key knowledge in risk management.

Sea level rise is a key issue in coastal zone management. In a European context this is examined in an integrated way in the Interreg IIIB project SAFECoast (http://www.safecoast.org). This integrated way is guaranteed because all types of stakeholders are involved, new ideas about social cost benefit analysis are set up and flood probabilities are replaced by flood risks, taking into account the consequences of flooding. For river catchments the impact of climate change on flooding and low flow situations and deficits is much more unknown. One of the important reasons of this uncer-

tainty is the high importance of the surrounding area, differing from sub catchment to sub catchment.
This research could make use of previous studies about climate change for Belgium. Much effort is invested in statistical analysis to examine the possibility of trends and cycles in rainfall (Vaes et al., 2002). The Royal Meteorological Institute of Belgium (KMI) is already working on the link between atmosphere and hydrology since the first set of climate change scenarios was made available by the IPCC (Gellens and Roulin, 1998). Since then, the scope was further extended from relatively small river catchments towards the whole Meuse and Scheldt river basin. This research is based on transient experiments of General Circulation Models forced with increasing greenhouse gas content (Roulin et al., 2001, Roulin and Arboleda, 2002).

Based on these results a next step is working with Regional Climate Models. Much more atmospheric models became available and can be combined to investigate the uncertainty on the prediction. Flood damage and flood risk scenarios based on these future flood maps give much better insight in the effectiveness of measures taken and makes the water managers work more sustainable.

METHODS

Several aspects must be taken into account when creating a method for the quantification of the effects of climate change on the hydrological system. Climate and hydrology have to be modelled jointly together with their interactions. Besides empirical models, several models are available for physical based modelling of the climate system. They can operate under a wide variety of scales of space and time, like it is for hydrological models. Usually the scales of climate models are lager then those for hydrological ones, making *downscaling* necessary on the interface between the climate and hydrological models. (Boukhris et al., 2006a,b).

Several components have to be combined creating many possible methodologies. Some important aspects are:

- type of climate models: General Circulation Models / Global Climate Models (GCM’s) or Regional Climate Models (RCM’s);
- scenario’s for greenhouse gas emissions;
- scaling methods: dynamic scaling starting from GCM’s using RCM’s or statistical and empirical scaling including regression techniques, stochastic methods, selection of historical events, etc.

Perturbation factors – calculated average differences between a reference period and scenario simulations in terms of percentage – for Flanders has been made available by Van Ypersele and Marbaix (2004). They are based on GCM’s so in addition the *PRUDENCE* (http://prudence.dmi.dk) RCM simulation results for Flanders are derived by the KMI using 10 RCM’s with each time one to four simulations with different initial conditions. Cumulative rainfall volumes per season are used for comparisons between control period and scenarios. Intrinsic to this approach perturbation factors are assumed to be independent of the time scale used (Boukhris et al., 2006b) which has to be confirmed in the project Climate Change Impact on Hydrological extremes (CCI-HYDR: http://www.kuleuven.be/hydr/CCI-HYDR)

For each of the *PRUDENCE* RCM simulations rainfall and potential evapotranspiration (ETo) is derived together with climatologic variables necessary for the Bultot method (Bultot et al., 1983) for ETo. This method is used by the KMI for historical ETo calculations. Due to consistency reasons this method is used here and no direct use is made of the RCM model results (Boukhris et al., 2006b). An overview of the average, upper and lower boundary *PRUDENCE* RCM perturbation factors can be found in Table 1. Some of the climate simulations potentially could be rejected because their results significantly differ (in both directions) from those of the other RCM’s. Tested for consistency with historical data for a control period of 30 years (1960-1990) the results show large differences for all of the potentially rejected simulations so they are kept out of further analysis.

Table 1. Averages and upper and lower boundaries of the PRUDENCE RCM perturbation factors, after rejection of most inconsistent climate simulations

Variable	Hydrological seasons	Lower boundary	Average	Upper boundary
Rainfall perturbatio	Winter	1.00	1.08	1.16
	Summer	0.80	0.87	0.94
ETo perturbation	Winter	1.06	1.17	1.27
	Summer	1.04	1.15	1.25

The upper and lower boundary values in Table 1 cannot be seen as absolute values but must be interpreted as a high and low scenario where no probabilities can be associated with yet (Boukhris et al., 2006b). An interesting comparison can be made with the most recent Dutch climate scenarios of the Royal Dutch Meteorological Institute (KNMI). A combination of two elements is made in these scenarios: a moderate (1°C) or high (2°C) average temperature increase and a strong or less strong change in atmospheric circulation. The combination leads to 4 scenarios as shown in Table 2. However no information is available for winter ETo perturbation.

Table 2. Perturbation factors of the latest KNMI climate scenarios (KNMI, 2006)

Variable	Hydrological seasons	Moderate temperature increase, little changes in atmospheric circulation (G)	Moderate temperature increase, strong changes in atmospheric circulation (G+)	High temperature increase, little changes in atmospheric circulation (W)	High temperature increase, strong changes in atmospheric circulation (W+)
Rainfall perturbation	Winter	1.04	1.07	1.07	1.14
	Summer	1.03	0.90	1.06	0.81
ETo perturbation	Winter	-	-	-	-
	Summer	1.03	1.08	1.07	1.15

RESULTS

Based on the method described in the previous chapter and the methodology used at Flanders Hydraulics Research for hydrologic impact analysis (described in Willems et al., 2000) three test cases are done for the Dender catchment (see figure 1). NAM modelling (DHI, 2004) is done for all gauged sub catchments and based on empirical relations between model parameters and area properties for all other sub catchments (Rombauts and Willems, 2004).

The exercise is done stepwise for one of the sub catchments. Making a comparison between the hourly river discharge peaks versus the return period for the NAM models without perturbation, with only rainfall perturbation and with rainfall and evapotranspiration perturbations, river peak discharges increase when only rainfall perturbation is taken into account but decrease when evapotranspiration perturbation is added (see figure 2). The analysis shows that, based on *PRUDENCE* RCM's climate models and the seasonally perturbation factors assumed to be constant, it is quite unsure that climate change is responsible for an increase of flood probabilities and flood risks (Boukhris et al., 2006b). Flood risk is also dependent of the damage when a flood occurs so even if flood probability decreases, flood risk can increase when the vulnerability of the hinterland rises. This effect is important when taking measures for future but is outside the scope of this study.

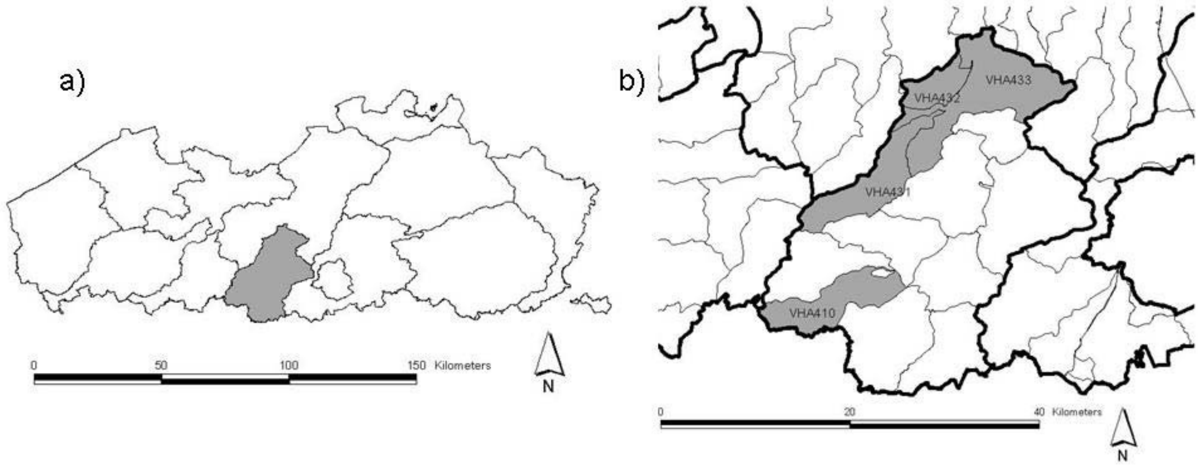

Figure 1. a) Overview of the 11 river catchments in Flanders, Dender catchment in grey, b) Sub catchments (VHA zones) in the Dender catchment, case studies in grey (VHA 431 and 432 taken as one test case).

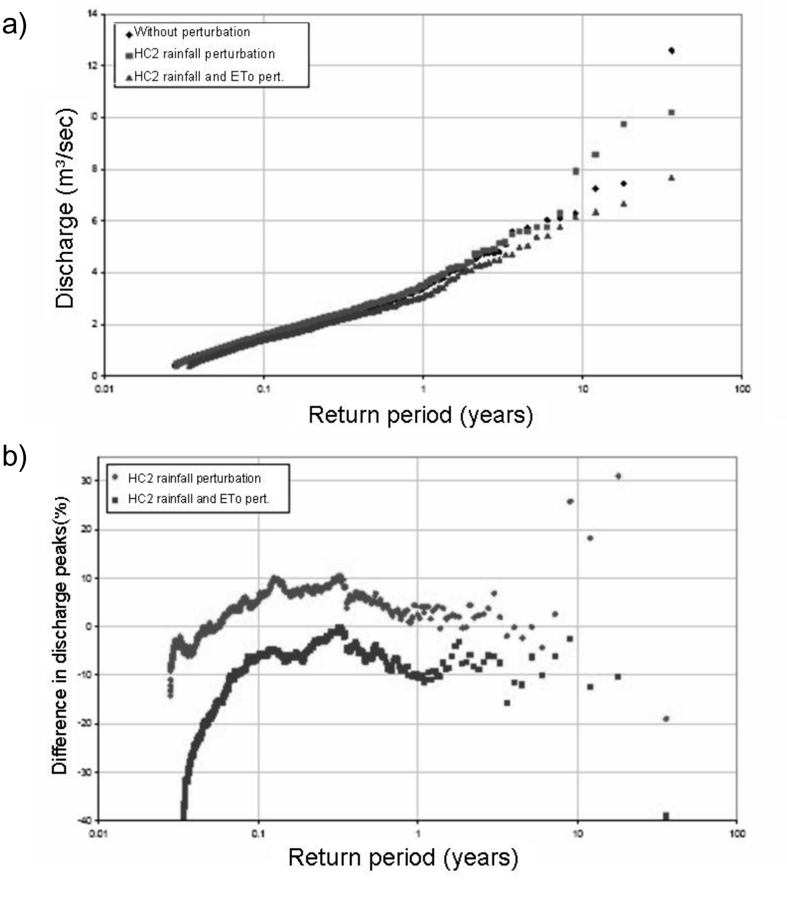

Figure 2. a) Hourly peak discharges versus return period for VHA410 zone with and without *PRUDENCE* HC2 rainfall and ETo perturbation factors, b) Difference in percentage for hourly peak discharge of *PRUDENCE* HC2 rainfall and ETo perturbation factors, both climate prognosis for 2100 (after Boukhris et al., 2006b).

In a similar way impact on low water discharge is studied (inverse discharge versus return period). It is clear that due to a decrease in cumulative rainfall volume (decrease in summer rainfall and increase in ETo) low water discharge diminish strongly for all aggregation levels. In a next phase the effect on overall water availability will be examined. The other two test sites give very similar results. A summarizing view of the results can be found in figure 3.

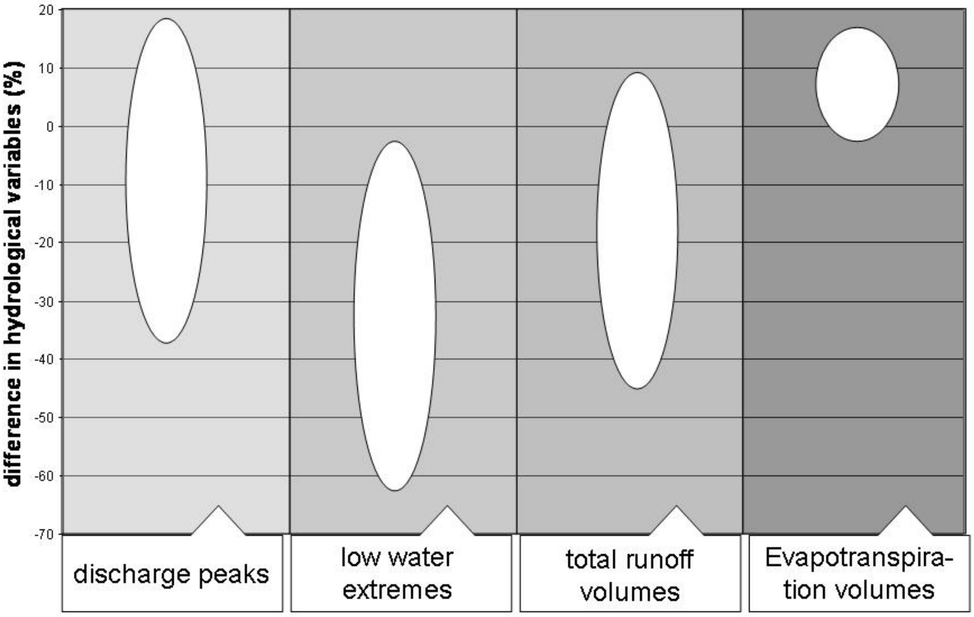

Figure 3. Average difference (%) in hydrological impact for VHA-zone 410 and rainfall and ETo perturbation for a low, middle and high scenario: climate prognosis for 2100 (after Boukhris et al., 2006b).

DISCUSSION AND CONCLUSIONS

The methods discussed above are a first step to take climate change effects on river discharges into account. The method uses seasonal average perturbation factors applied on time series of rainfall and potential evapotranspiration (ETo) as an input for hydrological models. Nearly independent discharge peaks and low water extremes (Boukhris et al., 2006b) can be selected to derive composite hydrographs. Different perturbation parameters are derived for summer and winter season (yearly two step variation). The perturbation factors are strongly dependent of the type of climate model and an increase in greenhouse gas emissions in the future (until 2100) is supposed. The uncertainty on perturbation factors is large, making the hydrological impact analysis of climate change uncertain.

The methodology is tested for some sub catchments of the Dender cachtment. In spite of large uncertainties some clear conclusions can be made. Based on the test cases low water discharges diminish for all considered climate simulations. The situation of high water discharge is unclear. Both simulations with a positive and negative trend can be found. The trend in peak discharge is dependent of the relative importance of the increase in winter rainfall compared to the decrease in summer rainfall and of the relative importance of trends in rainfall versus increase in evapotranspiration (Boukhris et al., 2006b). Drought problems will be more severe in future and will become more important than flood problems. Uncertainty on hydrological impact results is reduced by rejecting models with significant differences compared to a recent historical control period. The criterion of large differences is not enough to conclude that these models can be rejected (there is no implication that the predicted effects of climate change are uncertain) so only those with extreme perturbation factors (outliers) are rejected.

The differences in impact results for the Dender catchment test case give an indication of the overall uncertainty. To make the calculation process faster to be able to repeat the exercise for all modelled catchments in Flanders in a continuation project (results expected in spring 2008) a simplified method with 3 simulations (a low, middle and high climate change scenario) is executed. This gives an indication of the uncertainty but abrupt changes in trends in hydro meteorological series are and will be very difficult to predict (Kroonenberg, 2006).

Present impact analysis is based on Ukkel rainfall (close to Brussels, longest available time series in Belgium) but spatial variation in Flanders exists. Potential variation in perturbation factors is outside the actual scope but is researched in the CCI-HYDR project and so are the differences between seasonal perturbation factors and perturbations of extreme rainfall and / or ETo conditions. In the actual methodology they are taken identically.

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Impact of Climate Change on hydrology and flooding in Songkhram River, Thailand

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Keywords: Climate change, flooding, Thailand, modelling

ABSTRACT

The effect of climate change on hydrology and flooding of the Songkhram River basin in Thailand was studied using a combination of a distributed hydrological model and a 3D flood model. The target basin, having an area of 13,138 km^2, is located in North-eastern Thailand and is a part of the Mekong Basin. The climate of the area is dominated by monsoon rains that create a yearly flood pulse and cause extensive flooding specially in the Lower Songkhram River area. The modelling tools used were distributed VMod hydrological model for the entire watershed and EIA 3D hydrodynamic model for the Lower Songkhram River basin floodplains and junction with the Mekong River. Impact of climate change was estimated using three climate scenarios calculated with the Conformal Cubic Atmospheric GCM (CCAM). These scenarios were A) baseline, B) baseline times 1.5 and C) baseline times 2 atmospheric carbon dioxide level.

As a result of the modelling study the impact of the climate change on discharge and flooding were obtained by comparing the scenario results to baseline. In both scenarios the local average and maximum discharges increased, while the average dry season discharge decreased in scenario B and increased in scenario C. In the flood simulation the flood levels and flooded areas in the Lower Songkhram River area increased considerably in the scenario C. The modelling results also showed that the flooding depends strongly on the water levels in the Mekong mainstream, which influences the floodplain through both backwater effect and reverse flow. It was concluded that the Mekong water level is the main factor defining the flood behaviour in lower Songkhram River.

The study is part of the MRC/WUP-FIN Lower Mekong Modelling Project; and USAID and IRG project on Climate Change Scenarios in the Lower Songkhram River Basin.

INTRODUCTION

The Songkhram River watershed is part of the Mekong River basin and has an area of 13,138 km^2 (Figure 1). The Songkhram River starts from the low mountains with elevation of 675 m and drains to Mekong in elevation of 135 m. The climate of the area is dominated by monsoon rains that divide the year to wet season from May to October, and dry season from November to April. One of the most important parts of the basin ecosystem are the extensive floodplains located mainly in the Lower Songkhram River area. This area is known from its rich fisheries. The high productivity of the floodplain depends on the flood pulse originated from the monsoon rains in the upper catchment and influence of the Mekong due to backwater impact and sometimes even reverse flow from the Mekong to the floodplains of Songkhram River (Kummu et al., 2006).

The floodplains of the Songkhram River watershed support several different kinds of livelihoods, such as fisheries and rice cultivation. Songkhram River area is one of the poorest areas in Thailand, and most of the development goals for the area are connected to the enhancement at agricultural and fisheries sectors (Kummu et al., 2006). Large amount of people in the area are directly dependent on the natural resources and thus, the possible changes in hydrological regime may have severe influences on the livelihoods of local people. Thus, it is important to understand how the possible climate change would impact on the hydrology and floods in the basin.

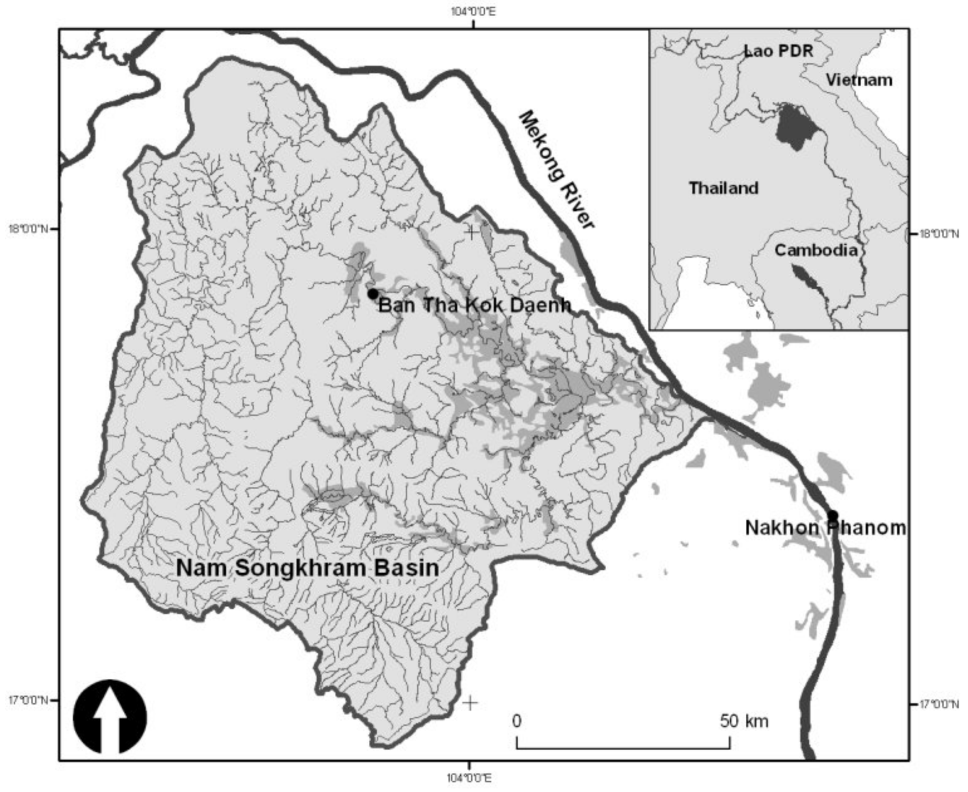

Figure 1. Location of the Songkhram River basin. The floodplain is marked with darker grey.

METHODS

The main aim of the project was to simulate the impacts of the climate change on the hydrology and flooding in the Songkhram River Basin. The simulations were performed in local scale with a hydrological and a hydrodynamic flood plain model that used climate scenarios obtained from larger scale model as input and boundary data.

Climate scenarios

As an input data for the model simulations, three climate scenarios calculated with the Conformal Cubic Atmospheric GCM (CCAM) were used. The CCAM model is developed and run by Australian Commonwealth Scientific and Industrial Research Organization (CSIRO), and re-scaled for the Southeast Asia region by SEA START RC (Chinvanno and Snidvongs, 2005). CCAM is a global atmosphere-only model and can be driven by boundary conditions from a global climate model (including ocean, atmosphere, ice and land) (McGregor and Dix, 2001).

The baseline condition for running the model is atmospheric carbon content that compares with the situation of 1980's (Chinvanno and Snidvongs, 2005). The atmospheric model CCAM was used to simulate climate conditions with three different levels of Atmospheric Carbon content:

- Scenario A: Baseline period on 1980 – 1989 (atmospheric carbon content 360 ppm)
- Scenario B: Atmospheric carbon content 1.5 x compared to the baseline (540 ppm)
- Scenario C: Atmospheric carbon content 2 x compared to the baseline (720 ppm)

Spatial resolution of the produced climate data was 0.1 degrees and time resolution one day. The data included daily values of precipitation, maximum and minimum temperatures, solar radiation and average wind speed. Compared to baseline scenario A, the precipitation increased in scenario B by 2-3%, and in scenario C by 8-12 % depending on the location. The climate scenario data was used directly as input for the hydrological model and the precipitations were scaled to fit the observed precipitations by multiplying them with a constant.

Basin wide impact – Mekong influence

The Mekong discharge for different climate scenarios was calculated by the SEA-START RC team by using the VIC (Variable Infiltration Capacity) hydrological model for the whole Mekong basin (see e.g. Liang et al., 1994). As a result, ten years monthly average discharges were obtained for each scenario. For this study the Mekong discharges for baseline scenario A were constructed from actual discharge observations. For scenarios B and C the discharges were computed by multiplying the observation data with monthly average percent change computed from the VIC model results. The resulting Mekong discharges are presented in Figure 2. The scenario B (1.5 X) gives smaller discharges during peak flow (September) than baseline scenario. However, the scenario C (2 X) gives much higher discharges during the whole wet season compared to the baseline. The changes during dry season are small in absolute values in both scenarios.

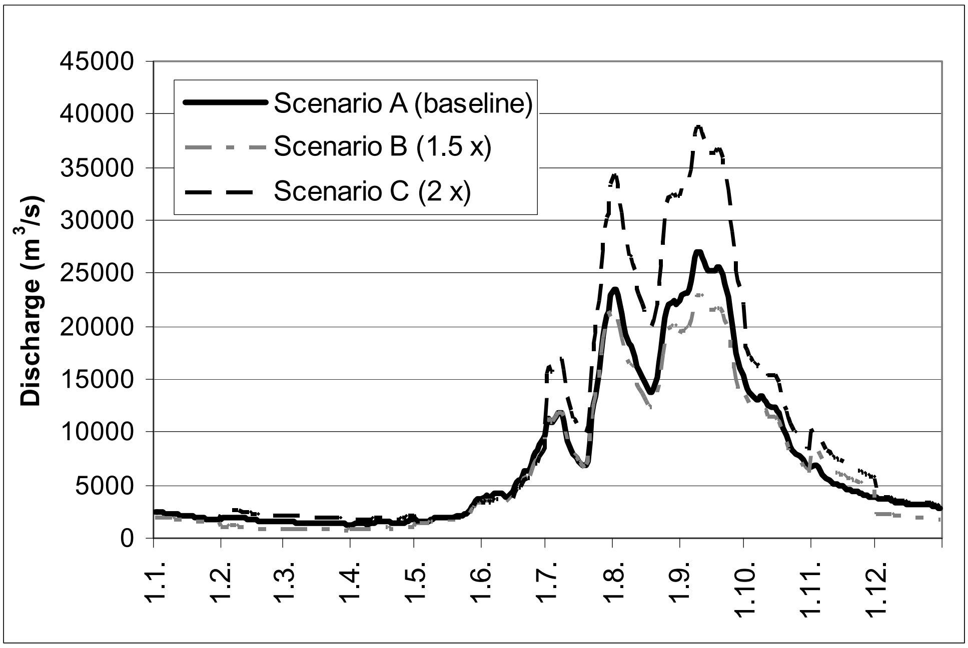

Figure 2. Climate change impact on Mekong discharge in the mouth of Songkhram River during a wet year (1980).

Modelling tools

The Songkhram basin was simulated using a distributed hydrological model Vmod for the entire watershed and a 3D hydrodynamic model called EIA 3D model for the flood plain. The EIA 3D model was set up for the Lower Songkhram River basin floodplains and junction with the Mekong. Both of the models are developed by Environmental Impact Assessment Centre of Finland Ltd.

The VMod model is a distributed physically based/conceptual hydrological model based on grid representation of the modelled catchment (MRC/WUP-FIN, 2006b). Hydrological processes in the catchment are simulated using simplified physically based formulations. The Songkhram River model has 1 km by 1 km grid resolution, and there are 13,128 active grid cells. The model river network was calculated from a 50 m resolution DEM and corrected using the digitized real river network. The model was calibrated based on weather and discharge observations of 1989-1991 and verified against observations of 1992-1995.

The EIA 3D model is a 3-dimensional hydrodynamic model that computes water level and water flow in the modelled area (MRC/WUP-FIN, 2006a). The model was set up for the lower part of the Songkhram River Basin. The boundary conditions for the Songkhram River and it's tributaries were the discharges from VMod hydrological model and the upper boundary condition for the Mekong were the discharges of Mekong at Nakhon Phanom based on observations and the results of the VIC model. The lower boundary condition for the Mekong was the rating curve in Nakhon Phanom based on water level and discharge observations.

The EIA 3D model system is fully three-dimensional finite difference model based on rectangular grid representation of the target area. The model system accommodates meteorological, hydrological, topographic, land use and infrastructure characteristics and produces 3D hydrodynamics and water quality as a result. The modelling platform includes data processing, model control, GIS, database control, model data products and visualization (Koponen et al. 2005; MRC/WUP-FIN, 2006a). The EIA 3D model area for Songkhram River is rectangle with dimensions 113 km times 55 km. The grid resolution is 500 m meters for the floodplain and 50-500 m for the rivers and channels. River widths and bottom depths for the Songkhram River and its tributaries are based on the channel cross section data from TNMC and the Mekong River bathymetry data are from the Hydrographical Atlas produced by MRC. The model has been calibrated and verified against water level observations and satellite data of the flood extent.

RESULTS

As a result of the modelling study the impact of the climate change on discharge and flooding were obtained by comparing the scenario results to baseline scenario A.

Climate change impact on local hydrology

The results of the climate change impact on the hydrology in Ban Tha Kok Daeng (location in Figure 1) are presented in Table 1. The average discharge would increase in 8.4% scenario B and in 23.1% scenario C. These can be compared to the increased precipitation as presented in Table 1. The increase in the discharge is 2-2.5 times larger than increase in precipitation in both scenarios, is most likely due to saturation of the soil. The average dry season (Dec-May) discharge increases in scenario B while it decreases in scenario C. This might be connected to the increased evaporation in scenario C or the change in timing of the high flows. In both scenarios the average minimum yearly discharges decreased. The average wet season (June-Nov) discharge increases 7.9% and 23.6% in scenario B and C, respectively.

Table 1. The hydrological characteristics for the baseline and the two climate scenarios in Ban Tha Kok Daeng during the 1980-1989.

	Baseline scenario A Discharge m^3/s	Scenario B Change (%) from scenario A	Scenario C Change (%) from scenario A
Average precipitation	1628 mm/a	3.3 %	8.8 %
Average discharge	115	8.4 %	23.1 %
Average yearly maximum discharge	533	7.2 %	10.6 %
Average yearly minimum discharge	0.05	-31.0 %	-3.4 %
Average dry season discharge	2.3	54.7 %	-31.4 %
Average wet season discharge	226	7.9 %	23.6 %

Climate scenario impact on flooding

The impact on flooding depends on the year, whether it is wet, average, or dry. The most significant changes in flood characteristics occurred during the wet year. However, the overall patterns of the changes were similar for all the years: the floods were smaller during the scenario B and larger during the scenario C. The water levels in the floodplain, especially the peak water level, decreased in scenario B some tens of centimetres while the water level increases even by 2 m in the scenario C. These changes are due to the impact of climate scenario in Mekong mainstream water level, since the water level in the floodplain is mainly controlled by the water level in the Mekong mainstream. Figure 3 shows the simulated maximum water extent and flood depth in the three scenarios during a wet year.

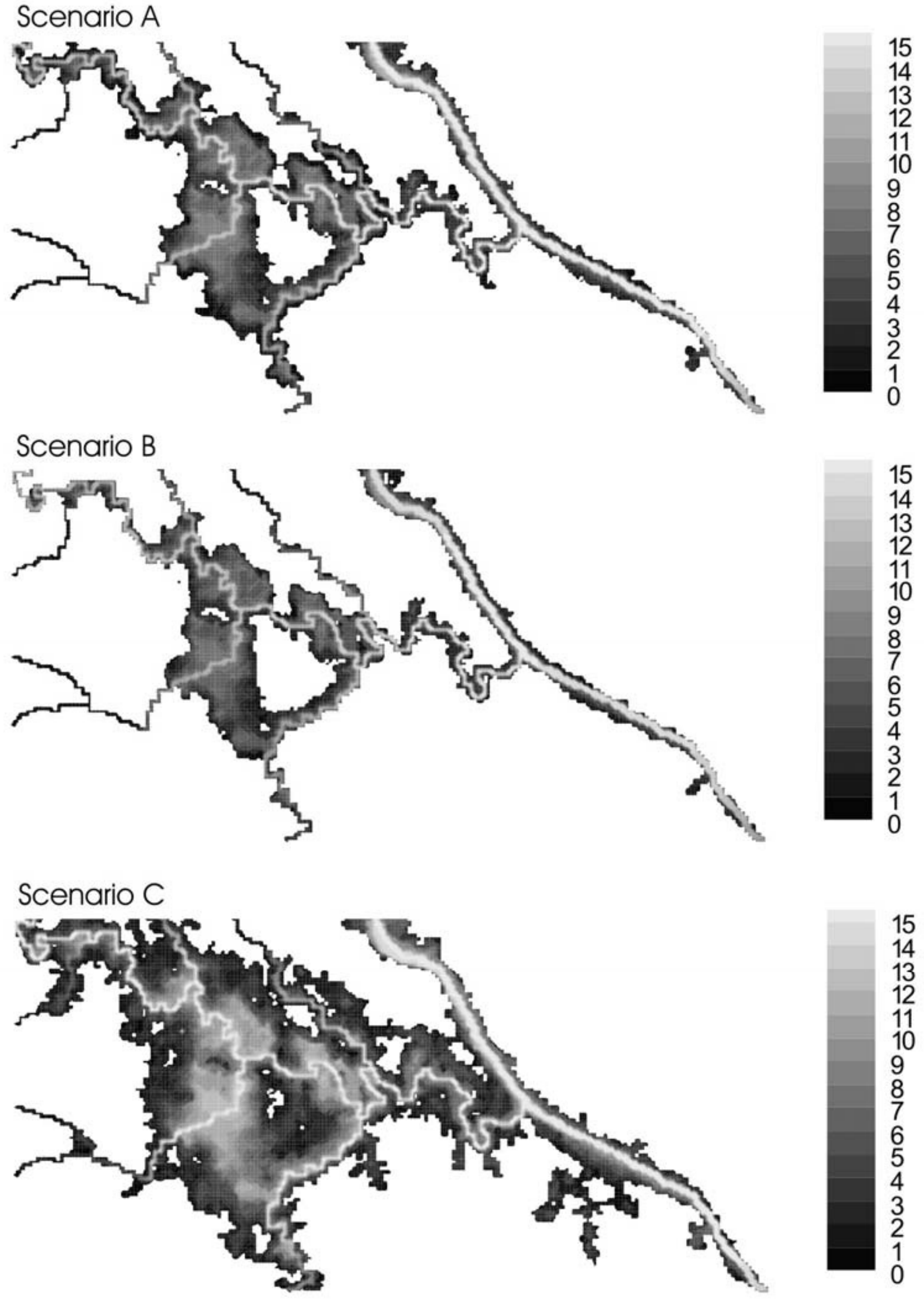

Figure 3. Simulated maximum flood extent and flood depth (in meters) in the Lower Songkhram River in three scenarios during a wet year (1980).

DISCUSSION AND CONCLUSIONS

In both climate change scenarios the local average and maximum discharges increased, while the average dry season discharge decreased in scenario B and increased in scenario C. Based on the simulations the flooded area, flood height, and flood duration would increase in significantly scenario C but decrease in scenario B.

The modelling results also showed that the flooding depends strongly on the water levels in the Mekong mainstream, which influences the floodplain through both backwater effect and reverse flow. The Mekong water level is the main factor defining the flood behaviour in lower Songkhram River and the impact of local upstream flood control on flooding would be negligible. It is therefore crucially important to understand the impact of climate scenarios on Mekong mainstream water levels in order to be able to predict the impacts of the climate change on the flooding in the floodplains of Songkhram River. The changes in Mekong discharge estimated with the VIC model are the most important input to the modelling of the lower Songkhram River and these results and the assumptions in applying them should be examined more closely in further studies.

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Climate change effects on extreme floods in Finland

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Keywords: design floods, extreme floods, climate change, Finland, dam safety

ABSTRACT

Effects of climate change on extreme floods used as design floods for high hazard dams were evaluated in Finland. The design floods were first estimated for the baseline period (1961-2000) and then for future climate of 2070-2100 using model simulations based on design precipitation concept. The hydrological catchment models of Watershed Simulation and Forecasting System (WSFS) were used for the simulations. In the method, two weeks design precipitation was combined with 40 years of observed daily precipitation and temperature data. and the most critical timing of the design precipitation in this period was searched. The largest simulated flood was considered to be the design flood with a return period of 5 000-10 000 years. For six dams, the baseline design floods were compared with floods estimated with three different frequency distributions to check if the simulated design floods of the baseline period were of correct magnitude.

The effect of climate change on design floods was evaluated by comparing the simulations in the climate of 2070-2100 to the baseline simulations. The climate change up to 2070-2100 was taken into account by changing the daily baseline temperatures and precipitations according to five climate scenarios with delta-change approach and changing the design precipitation according to two projections.

The design floods increased on the majority of the 34 high hazard dams. The change in design floods varied depending on the site of the dam, the type of the basin and on the primary cause of the flood. In northern Finland the design floods were caused mainly by spring snowmelt even in the changed climate. These design floods stayed on average unchanged, but there were large differences between results from different scenarios. In southern and western Finland, the design floods were mostly summer floods partly due to the storage capacity and regulation possibilities of the reservoirs above the dams. These summer and autumn design floods increased by 2070-2100 due to the increase in design precipitation.

INTRODUCTION

Climate change will impact floods in Finland in many ways. Average and extreme precipitations will increase (IPCC, 2002) and this may lead to increase in rainfall floods especially during summer and autumn. Warm spells during winter would increase winter floods. On the other hand, most extreme floods in Finland are now caused by snowmelt during spring. These floods will probably decrease, because increased temperatures will decrease the amount of snow. The effect of climate change on extreme floods in Finland is therefore not straightforward and varies in different parts of Finland.

The object of this study was to evaluate the effects of climate change on the design floods of high hazard dams in Finland. Dams in Finland are classified as high hazard dams if there is risk to human life or health or considerable and obvious risk to property and environment in the case of dam failure (Ministry of Agriculture and Forestry, 1997). High hazard dams are designed to withstand floods with return period of 5 000 to 10 000 years.

The research has been done in the Finnish Environment Institute in the Hydrological Services Division. The research has been a part of Dam safety and Climate change-project financed by the Finnish Ministry of Agriculture and Forestry and a part of Climate and Energy (CE)-project financed by Nordic Energy Research.

METHODS

The effects of climate change on extreme design floods were evaluated on 34 high hazard dams in Finland. These dams are located in different parts of Finland and have runoff areas varying in size from 0.7 km^2 to 61 000 km^2. Many of these dams are regulating a reservoir or a lake.

The Watershed Simulation and Forecasting System (WSFS) developed and operated by the Finnish Environment Institute (Vehviläinen et al., 2005) was used to make the model simulations. The WSFS is a conceptual watershed model based on the Swedish HBV-model.

The extreme floods used as design floods were evaluated using a method applied from the Swedish design flood calculation method described in the Swedish guidelines for design flood evaluation for large dams (Flödeskommittén, 1990). The method has been modified to suit better the needs of this study. In this method the design floods were simulated by combining rare weather condition in the most critical way. The 14 day long design precipitation period, which has a return period of about 1 000 years, was moved day by day through 40 years temperatures and precipitations based on observations and the timing of the design precipitation that produces the most severe flood was searched. This flood was considered to be the design flood with a return period of approximately 5 000 to 10 000 years. The simulated extreme floods of the baseline period were compared with floods estimated with frequency distributions to establish that the present day design floods had the correct return period for design floods of high hazard dams (in chapter results).

The magnitudes of the design precipitations were calculated from a report by the Finnish Meteorological Institute (Solantie and Uusitalo, 2000). The design precipitations have a return period of approximately 1 000 years and are an average areal value for the entire watershed. The magnitude of the design precipitations depend on the time of year, the area of watershed and location in Finland.

Climate change effects

The design floods were first simulated in the baseline period of 1961-2000 using measured weather data and the design precipitation. Then the weather data and the design precipitation was changed according to the predicted climate change effect by 2070-2100 and the same calculations were repeated. The assumption was that the return period of the floods in the two periods was the same. These floods of the two periods were compared to get an estimate on how the design floods change due to climate change.

Climate change by 2070-2100 was taken into account by changing the areal temperatures and precipitations based on observations of 1961-2000 with the delta-change approach and by changing the magnitude of the design precipitation period. The calculations were done with five climate scenarios and two changes of the design precipitation to gain an understanding of climate change related uncertainties. The climate scenarios used were from HadCM2 with the emission scenario IS92a for 2070-2099 (Tuomenvirta et al., 2000) and from regional climate model RCAO (Rummukainen et al., 2001) developed at Rossby Centre with boundary conditions from GCM's HadAM3H and ECHAM4/OPYC3 with emission scenarios A2 and B2 for 2071-2100 (Table 1).

Table 1. Climate scenarios

Abbreviation	Climate model	Emission scenario
HadCM2	HadCM2	IS92a
RH A2	RCAO/ HadAM3H	A2
RH B2	RCAO/ HadAM3H	B2
RE A2	RCAO/ ECHAM4/OPYC3	A2
RE B2	RCAO/ ECHAM4/OPYC3	B2

The changes in design precipitation caused by climate change were evaluated separately since the design precipitation, which is a rare extreme event, will probably change differently than the average precipitations (IPCC, 2002). The changes in design precipitations by 2070-2099 were evaluated in a Finnish Meteorological Institute report (Tuomenvirta et al., 2000), where results from HadCM2 global climate model with emission scenario IS92a were used. Two different increases of the design precipitation were used in this study; the smaller changes with increases from 12 to 40 % compared with design precipitations of the baseline period and the larger changes with increases from 35 to 60 % for large areas and from 35 to 85 % for small areas (Figure 1). The smaller increases were the averages of the grid cells in and close to Finland and the larger increases were the values which Tuomenvirta et al. recommends to be used.

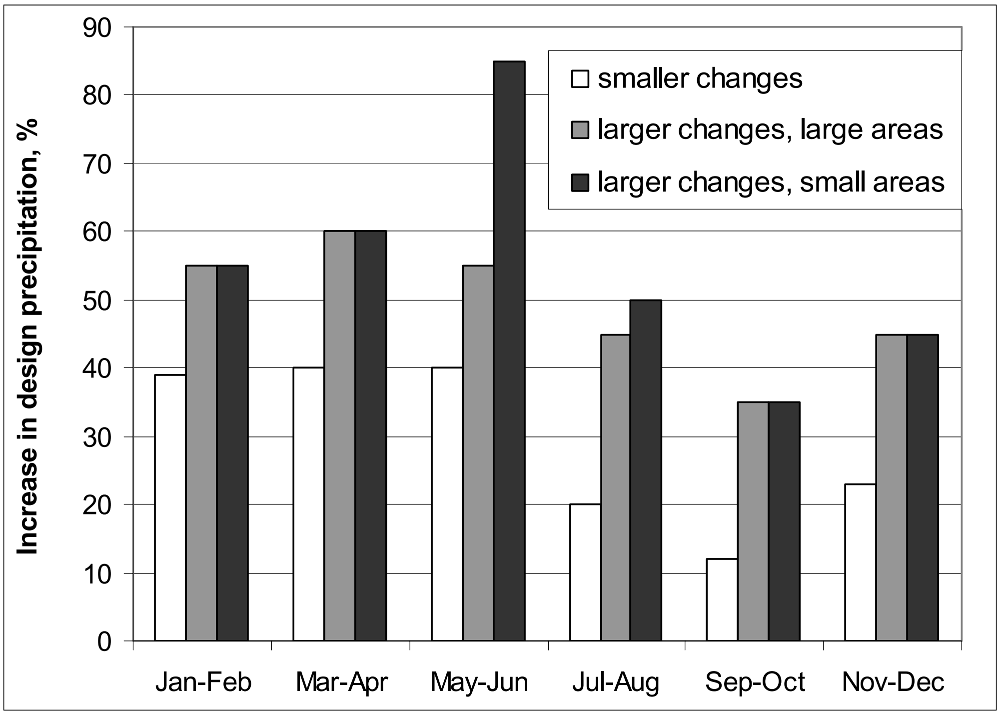

Figure 1. Changes in design precipitation from baseline period 1961-1990 to 2070-2099 with different projections and different areas.

For comparison, the changes of extreme precipitations were also analysed from the results of the four RCAO model climate scenarios (RH A2 and B2, RE A2 and B2). These results were however not used in the simulations, because this data was only available well after the beginning of this research. The changes in the 1 000 year daily maximum precipitation of the four climate scenarios were estimated with the Gumbel distribution. These changes had a large range depending on the scenario, month and grid cell in question. The changes evaluated from the HadCM2 model results used in this study fell mostly somewhere between the 75th and the 95th percentile of the RCAO results for the larger increases of design precipitation and between the 50th and 75th percentile for the smaller increases. Evaluating the changes of the design precipitation from several climate scenarios would therefore increase the range of changes, especially to smaller changes than the ones used.

RESULTS

It was important to establish that the return periods of the simulated floods in the baseline period were of correct magnitude to be used as design floods for high hazard dams. Therefore the simulated design floods of the baseline period were compared with 5 000 and 10 000 year flood estimates made with frequency distributions on six dams. On these dams there were enough discharge observations (39-95 years) and the assumptions of independent and random observations were met. The three frequency distributions fitted to the yearly maximum discharges were Pearson type 3, log-Pearson type 3 and Gumbel distributions.

The estimates for 5 000 and 10 000 year floods were compared with the simulated design floods (Table 2). The frequency estimates were of the same magnitude or larger than the simulated design floods with Gumbel distribution and of the same magnitude or smaller with Pearson 3 and log-Pearson 3 distributions. The differences between the different frequency distributions were large due to different coefficients of skew and their effect on the extrapolation of the distributions to very large return periods.

Table 2. Design floods of six dams and the 5 000 and 10 000 year flood peak estimates with three frequency distributions for the same locations. Units in m^3/s.

	Gumbel		**Log-Pearson 3**		**Pearson 3**		**Design flood From model simulations**
Return period	**5 000**	**10 000**	**5 000**	**10 000**	**5 000**	**10 000**	
Valajaskoski	7 215	7 620	6 239	6 491	5 910	6 125	6 188
Isohaara	7 996	8 433	6 256	6 425	6 017	6 180	6 860
Pahkakoski	1 916	2 024	1 595	1 652	1 511	1 561	1 524
Raasakka	2 310	2 438	2 037	2 124	1 920	1 991	2 260
Harjavalta	1 553	1 637	1 063	1 077	1 104	1 127	1 322
Kaltimo	822	934	714	730	753	776	860

The design floods occurred during summer and autumn on most of the dams in southern and central Finland both in baseline period and in 2070-2100. This was partly caused by the storage and regulation of the dam reservoirs, since spring floods were partly stored in the reservoirs that were emptied during winter. In northern Finland design floods in the baseline period were spring floods caused by combination of snowmelt and rainfall. In northern Finland the simulated design floods remained spring floods even in 2070-2100. In some dams central and eastern Finland the timing of the design floods changed from spring floods in the baseline period to summer or autumn floods in the future.

The changes (in percentages) in the simulated design floods of 2070-2100 compared with design floods in the baseline period are shown in Figure 2. The effect of climate change on design floods depends on the main cause of the flood. On dams in northern Finland, where the design floods were caused by combination of snow melt and rainfall also in the conditions of 2070-2100, the floods do not on average change much. This was because the warmer winters with less snow were partly compensated the increases in winter and spring precipitations. On the other hand, on dams in western and southern Finland, where the design floods were summer or autumn floods both in baseline period and in the future, the design floods increased. These increases were due to the significant increases of the design precipitation. On dams in eastern Finland, where the timing of the design floods changed from spring to summer by 2070-2100, the change in design flood varied from decrease to increase depending on the scenario and on how dominant the spring flood was in the baseline period. At two dams with large lakes and large runoff areas in south-eastern and southern Finland, the design floods increased considerably and the timing of the design floods changed to winter.

The smallest design floods in Figure 2 were generated with the smaller increases in design precipitation and the largest design floods with the larger increases. The climate scenario that generated the smallest and largest future design floods was different depending on the location and properties of the dam site and the timing of the flood. For example in northern Finland the smallest design floods in 2070-2100 were generated by the HadCM2 scenario with small increases in winter precipitations, whereas the largest design floods were by either scenarios with large increases in winter precipitation (RE B2) or scenarios with small increases in temperature (RH B2).

The largest changes in design floods (Figure 2) represent the probable upper limit for the change in design floods due to climate change, since the increases in design precipitation used were large. The smaller changes in design floods on the other hand do not represent the lower limit, since average increases of design precipitation were used. Even smaller design floods in 2070-2100 are possible and on many dams the smaller changes in design floods may the more probable ones.

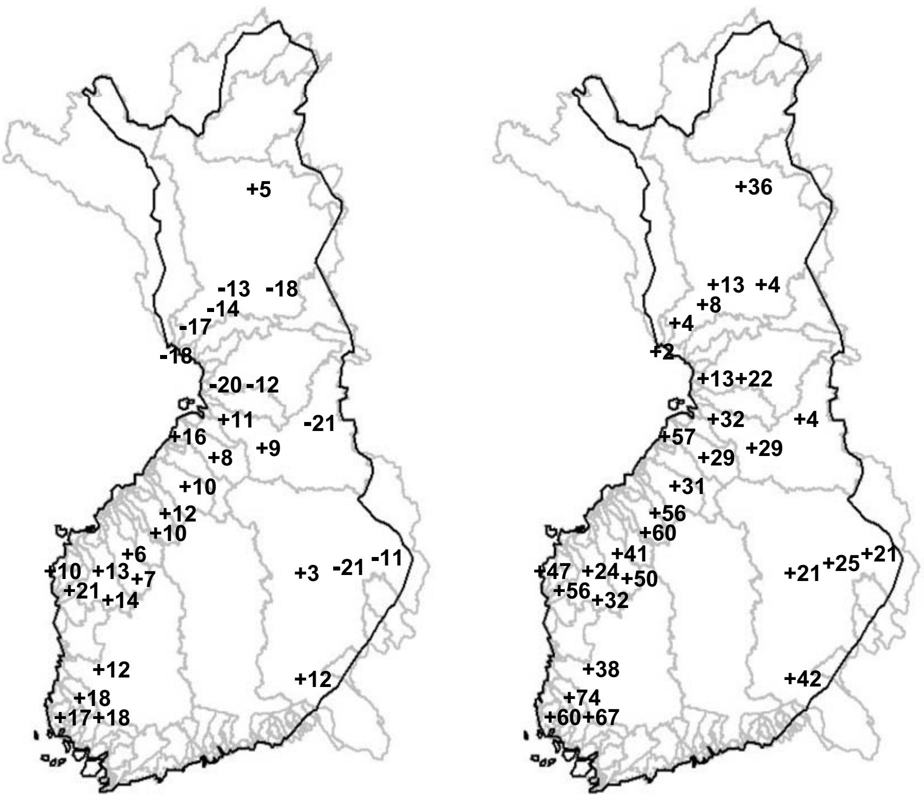

Figure 2. The change in percentages in design floods from baseline period to 2070-2100. Smallest design floods out of the floods simulated with ten different scenarios on the left and largest design floods on the right.

The main cause of the changes in summer and autumn floods were the increase in design precipitation. The magnitude of the spring floods depended strongly on the temperatures during winter and spring and therefore the climate scenario used had a large effect on the results. In large watersheds, where the design floods lasted for a long time due to the long lake routes, the differences between climate scenarios were large even in summer and autumn floods.

Sensitivity analysis of the design floods was also performed. The design flood magnitudes were influenced strongly by changes in the design precipitation; 10 % increase or decrease in design precipitation increased/decreased the design flood by 4-11 %. The largest changes with the change in design precipitation were in summer design floods on small watersheds with small storages. The smallest changes of the design floods were in spring floods, where snow melt made up large part of the flood. Changes in temperatures had little or no effect on summer and autumn floods, but affected the magnitude of the spring floods strongly.

DISCUSSION AND CONCLUSIONS

The range of change in design floods due to climate change was large on most of the dams due to the differences in the scenarios used for 2070-2100. In spite of the large range of changes, there were consistent increases on the majority of the dams. The entire range of uncertainties in the change of design floods due to climate change is even larger than the range in the simulations, because only three climate models and emission scenarios and two changes of extreme precipitation were used. There are climate models and emission scenarios that produce both larger and smaller changes in temperatures and precipitations than those scenarios used in this study. The design precipitation change was evaluated with only one climate scenario. Including results from other climate scenarios would increase the range of change in the design precipitations due to climate change and hence increase the range of change of the design floods. In addition, there are uncertainties in the model simulations. Only one set of model parameters were used and the model was used to simulated floods far larger than those it has been calibrated against.

The results can be used to identify the dams where climate change may cause increased risks of dam failure due to increases in extreme floods. The results are specific for the sites and return periods in question and they cannot be generalized. Precipitations with smaller return period will probably not change as much as the design precipitations. Floods that are more frequent than these design floods may change differently than the design floods.

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Drought and extreme precipitation in Finland

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ABSTRACT

According to Köppen's climate classification, Finland belongs wholly to the temperate coniferous-mixed forest zone where the rainfall is, on average, moderate in all seasons. However, even in this moderate climate we experience periods with excess precipitation and on the other hand several months with almost no precipitation at all. In this study we have examined the probability of drought and heavy precipitation in Finland. The return level estimates for the length of drought periods have been calculated based on measurements made at 12 locations in different parts of the country. In the case of precipitation the return level estimates of monthly precipitation were examined based on measurements made at about 200 stations beside the 12 same locations that were used for the examination of drought. The analyses of return levels were based on the statistical methods used in extreme analyses like GPD (General Pareto Distribution). According to the analyses during summer season once in ten years the length of period with precipitation sum below 10 mm is approximately 40 days and once in 100 years about 60 days. These values naturally vary regionally. Similar analyses were made using thresholds 25, 50, 100 and 200 mm. When the precipitation amount was analysed it was found that the 100-year return level of the monthly precipitation can at some location in Finland reach 290 mm. If we examine the situation at the 12 locations used for drought analyses then the once in hundred years level is 150-200 mm. The ten year return period level of the daily precipitation level at the studied 12 locations is about 55 mm and hundred year level around 80 mm, varying from one location to another.

INTRODUCTION

The occurrence of a large number of tropical storms in the Caribbean and even one near the Canary Islands in the eastern Atlantic, covered extensively by the media, have also raised a lot of discussion about the risk of extreme weather events here in Finland. In media reports, the occurrence of these events is frequently linked with the anticipated climate change caused by the intensified greenhouse effect.

In Finland we do not experience tropical storms or as large rainfall amounts as in the tropics. However, even here weather may cause considerable damage. In 1866-1868 about 8% of the population died due to extremely cold conditions during the spring months (e.g. Jantunen and Ruosteenoja, 2000; Turpeinen, O., 1986); in 1890 a very intense storm struck the southern coast of Finland and caused widespread damage; in September 1982 a storm known as Mauri brought down several million cubic metres of forest in Northern Finland; in November 2001 storms known as Pyry and Janika felled more than 7 million cubic metres of forest in Northern Finland (Metsätuhoryhmä, 2003); the drought that started in 2002 caused damage estimated at about 102 million Euros (Silander and Järvinen, 2004); in January 2005 a storm hit southern Sweden and brought down more than 70 million cubic metres of forest (Alexandersson, 2005) and related to this low pressure area the sea water level rose to a record high and dangerous level even in Helsinki.

Earlier studies of the occurrence of extreme weather conditions in Finland have been relatively few. Alexandersson et al. (1998) and Bärring and von Storch (2004) have studied storminess in Northern Europe. Heino et al. (1999) studied climate extremes in Northern and Central Europe, Tuomenvirta et al. (1998) have studied extreme temperatures at high latitudes in Europe, while Tveito et al. (1998) published an Atlas of Climatic Extremes in Nordic Countries. Makkonen (2006) has examined the different methods and uncertainties related to extreme weather analyses.

The cornerstone of estimation of extremes using statistical methods is the theory of three distribution types presented first by Fisher and Tippett (1928) and proved by Gnedenko (1943) and later more elegantly by de Haan (1976). This theory was first applied with fixed interval extremes like annual extremes that led to the generalized extreme distribution (GEV). Afterwards the development of methods using values exceeding a threshold has become more relevant and led to the development of generalized Pareto-distribution (GPD). In the Finnish Meteorological Institute software know as eXtremes is utilized (e.g. Katz et al., 2005). This software includes possibilities to use either GEV or GPD distributions.

The aim of this study has been to examine the occurrence of droughts and excess rainfall in Finland. The study is a part of the Finnish Climate Change Adaptation Research Programme ISTO. To be able to examine the impacts of climate change, the limits of climate variability should be known. Especially the knowledge of frequencies of extreme and rare weather events is still to large extent missing due to relatively short observation time series. This present study aims on fulfilling one small part of this shortage.

METHODS

In this study the estimation of return periods of extreme precipitation and drought was done with help of the Extremes Toolkit-software that is developed in the National Center of Atmospheric Research (NCAR) (e.g. Gilleland et al., 2005; Katz et al., 2005). The software package includes options to use either GPD or GEV in analysing the return periods. At the moment GPD is probably more often used method than GEV. When using GPD a threshold value must be selected so that the distribution of extreme values is defined based on values exceeding the selected threshold. If the selected threshold is too extreme then the amount of remaining observation becomes too small and this results in a large uncertainty. On the other hand, if the threshold is too low then the distribution based on the data may not represent the really extreme cases (e.g. Coles, 2001). The Extremes Toolkit includes also a tool that helps to find the correct threshold value.

The reliable estimation of return levels for periods of several hundreds of years would require long, homogeneous measurement time series. Unfortunately reliable data is available only for about few decades. Most of the data available in database in Finland is approximately from 1960 onwards. The monthly precipitation measurements begun at many locations already about 100 years ago (Table 1 and Figure 1). Beside the 12 stations given in Table 1. the monthly precipitation was analysed in this work also by using all other available monthly precipitation measurements (more than 200 stations). In these analyses all the data were put together and the analyses gives an estimate about conditions in some locations in Finland as the analyses done using the 12 stations gives an estimate about conditions in a certain location. The longest daily data set used in this study started in 1947 (Joensuu) and the longest monthly data set started in 1844 (Helsinki). Six hourly data is available only for years 1991-1998 at two locations (Jokioinen and Sodankylä).

The calculation of the length of dry spells was done using five different thresholds 10, 25, 50, 100, 200 mm. The parameter that we have studied was the number of consecutive days during which the sum of precipitation received remained below the defined thresholds. In Finland the precipitation amount during the winter months is typically much smaller than during the summer months. As for example from the point of agriculture or forest fire risk, the summer season is more interesting than winter and that is why the dry spell calculations were made separately for the summer season (May-September) and for the whole year.

Figure 1. Location of meteorological stations used in the study.

Table 1. The stations and the years used in the calculation of return periods of different precipitation sums (monthly, 14-days, 5days, daily, 6 hours) and dry spells.

	Station											
Parameter	Helsinki	Turku	Jokioinen	Utti	Jyväskylä	Kauhava	Joensuu	Oulu	Kuusamo	Sodankylä	Muonio	Ivalo
Monthly	1844-2004	1950-2006	1902-2004	1945-2004	1945-2004	1909-2004	1933-2004	1953-2004	1908-2004	1907-2004	1909-2004	1946-2004
14 days	1958-2006	1950-2006	1959-2006	1959-2006	1950-2006	1959-2006	1947-1999	1959-2006	1959-1999	1947-2006	1959-2006	1957-2000
5 days	1958-2006	1950-2006	1959-2006	1959-2006	1950-2006	1959-2006	1947-1999	1961-2006	1959-1999	1947-2006	1959-2006	1957-2000
Daily	1958-2006	1950-2006	1959-2006	1959-2006	1950-2006	1959-2006	1947-1999	1961-2006	1959-1999	1947-2006	1959-2006	1957-2000
6 hours			1991-1998							1991-1998		
Length of dry spells	1958-2006	1950-2006	1959-2006	1959-2006	1947-2006	1959-2006	1947-1999	1959-2006	1959-1999	1947-2006	1959-2006	1957-1999

RESULTS

Detailed results including confidence levels will be published by Venäläinen at al. (2007). However, here are some of the main findings. Among the studied 12 stations the 10 year return period value of monthly precipitation varied between 121 and 157 mm and for the 500 years return period between 153 and 222 mm. When we look at the daily values the 10 year return period varied between 39 and 57 mm and the 500 years return period between 65 and 147 mm (Figure 2). On average the 500 years return period level for monthly data was about 184 mm and for daily data 110 mm.

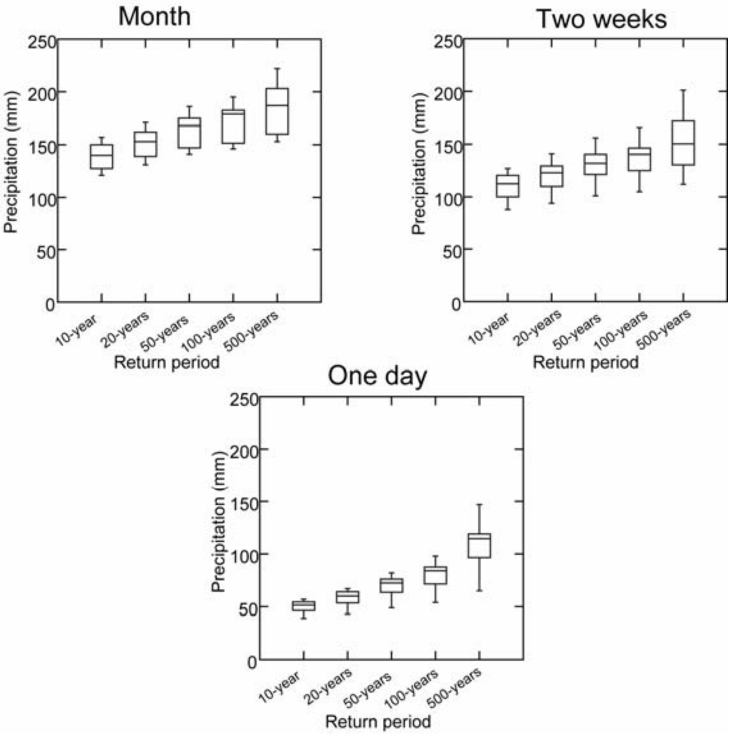

Figure 2. The variation of return level estimates for monthly, two weeks and daily precipitation amounts among the studied 12 stations.

In case we look at the return period levels of monthly precipitation calculated using all available data from more than 200 stations then the 10 year value was about 240 mm and the 100-year value about 290 mm (Figure 3). The difference between results based on the 12 station data and all available data demonstrate the difference in probability of an extreme event at a certain location compared with the situation of an extreme event anywhere in Finland.

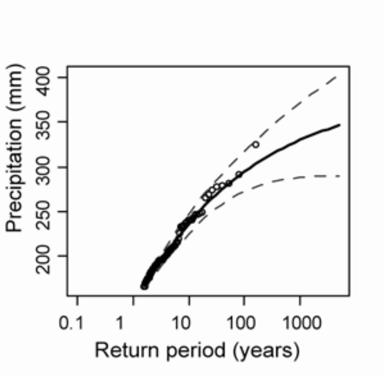

Figure 3. The return level estimates with 95 % confidence intervals (dashed lines) for monthly precipitation based on measurements made at more than 200 stations located in Finland. The longest time series is more than 150 years long.

The length of the period when the precipitation of consecutive days remained below 10 mm was around 50 days and the variation between the different locations was very small. The return period level once in ten years was 52 days and once in 500 years 64 days (Figure 4). If we look at drought below 200 mm then we found out that on average once in 500 years there was a period of 292 days with precipitation remaining below the threshold and once in ten years 251 days (Figure 4).

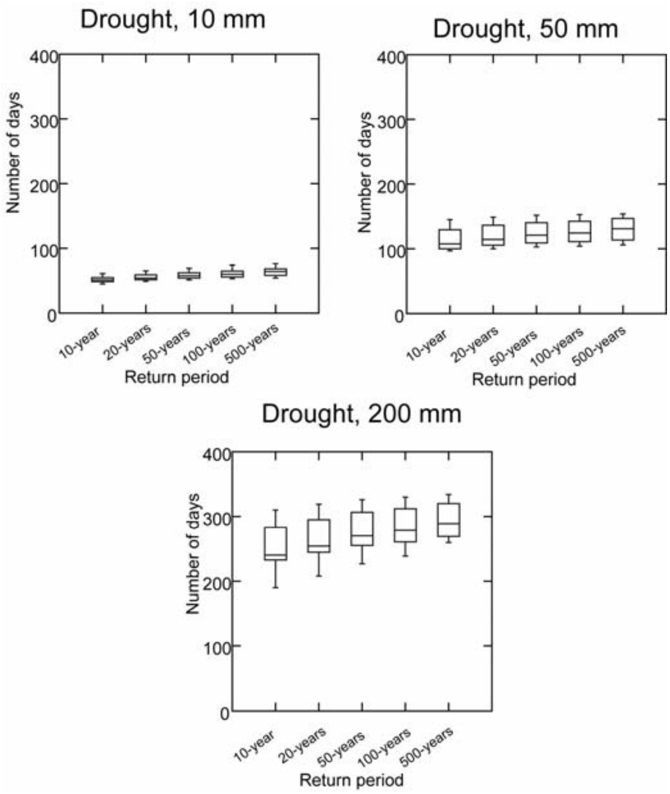

Figure 4. The variation of return level estimates for the length of dry spell lengths among the studied 12 stations in case of 10, 50 and 200 mm drought, i.e. the precipitation of consecutive days remained below those threshold values.

DISCUSSION AND CONCLUSIONS

The changing climate causes further challenges when calculating the return periods. This is a major problem in case of temperature variables. When we use e.g. past 150 years of measured temperature data we may notice that during the last few years we have measured so high temperatures that have return periods of several hundreds of years. However, if the change of climate is taken into account these high temperatures are no more that rare events. The change in precipitation patterns due to climate change in Finland is not as clear as in case of temperature. It is expected that especially during winter there will be more precipitation and during summer there may be more often very intensive precipitation events.

It is interesting to notice that there are quite large differences in the return levels between the 12 stations used in the study (Figures 2 and 4), i.e. the level that represents a 10 year return period at one station may be a 500 year level at another location. For example at Kuusamo the 500 year return period of drought below 50 mm was 106 days and at six other stations the 10 year value was as high or even higher. These differences may be caused not only by the spatial variation of climate but also by the relatively short measuring periods. The results of this study demonstrate the importance of long homogeneous measurement time series when the occurrences of extreme and rare weather events are examined.

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New developments of SimCLIM software tools for risk-based assessments of climate change impacts and adaptation in the water resource sector

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ABSTRACT

The purpose of this paper is to describe recent developments to SimCLIM, a software model system that simulates, both temporally and spatially, the impacts of both climate variability and change. These developments provide greater versatility in conducting climate impact assessments that span global, regional and local scales and that allow issues of adaptation to climatic risks to be examined through simulation techniques. In particular, these new tools allow the incremental risks and costs arising from climate change, as compared to those from current natural variability, to be identified and assessed. The new developments are illustrated in two examples: coastal flooding from tropical cyclones in the Cook Islands; and a SimCLIM linkage with Danish Hydraulic Institute (DHI) models and their application to a catchment in New Zealand.

INTRODUCTION

Throughout the world, climatic variability and extremes are commonly manifested in problems of water – either too much or too little. With future climate change, the problems could worsen considerably for many developed as well as developing countries. In recent years there has been an increasing realisation that the impacts of climate change which impinge most directly on people and communities will be felt largely as changes in the *risks of extreme events*, such as floods, droughts and tropical cyclones. Assessing and promoting *adaptation* should therefore focus, in the first instance, on climatic risks at the local level.

At this scale, one problem faced by decision-makers is how to assess the risks and the benefits and costs of adaptation. In particular, problems arise in attempting to differentiate the additional, or *incremental*, effects due to future climate change as opposed to current, natural climatic variability. In order to address this problem, an enhanced version of an integrated software model system, called *SimCLIM,* has been developed. In this paper, these software tools are described, along with two examples of their application.

METHODS

SimCLIM is an "open-framework" software system that can be customised and maintained by users for the purpose of examining the impacts and adaptations to climate variability and change, both spatially and temporally (Warrick et al., 2005). It was developed from a system originally built specifically for New Zealand, called CLIMPACTS (Warrick et al., 1996, 2001; Kenny et al., 1999, 2000), with subsequent versions for other countries and regions (for example, the Australian version, OzCLIM; CSIRO, 2004).

The SimCLIM system links and integrates complex arrays of data and models in order to simulate the impacts climatic variations and change, including extreme climatic events. As illustrated in **Figure 1 (left panel)**, SimCLIM has a vertically-integrated, "top-down" structure that links global, local and sectoral models and data for the purpose of examining impacts on, for example, agriculture, health, coasts or water resources. For generating scenarios of future climates, SimCLIM uses a "pattern scaling" method (Santer et al., 1990; Hulme et al., 2000; Carter and La Rovere, 2001) that involves the scaling of "standardized", spatial patterns of climate change from very complex General Circulation Models (or GCMs) with the time-dependent (e.g. year-by-year) projections of global-mean climate changes from simpler models. These changes are used to perturb the present climate (whether time-series data or a spatial climatology) and thereby create climate scenarios for a year of interest (e.g. 2050) (**Figure 1, right panel**). The SimCLIM user interface provides the user with considerable scope for choosing amongst global projections, GCM patterns, model sensitivity values and future time horizons, and thus for examining the range of uncertainties involving future greenhouse gas emissions and scientific modelling.

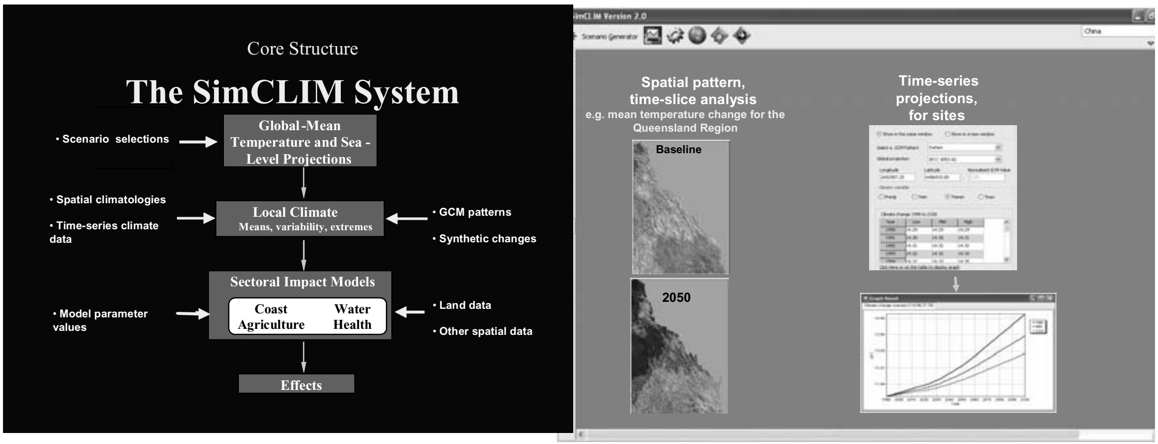


Figure 1: Left panel: the core structure of the SimCLIM system. Right panel: SimCLIM can be used to generate both spatial scenarios and projected time series of climate changes.

The "open-framework" features of SimCLIM are recent (Warrick et al., 2005; CLIMsystems, 2005). The distinctive advantage of the open system (as opposed to the older "hard-wired" system) is the flexibility afforded to users for importing their own data and models – much like a GIS. There are tools to allow the user to import: (1) spatially-interpolated climatologies and other spatial data (e.g. elevation surfaces); (2) site time-series data; (3) patterns of climate and sea-level changes from General Circulation Models (GCMs); (4) impact models that are driven by climate (and other) variables; and (5) shape files (e.g. boundaries, roads, streams). The geographical size is a matter of user choice (from global to local), as is the spatial resolution (subject to computational demands and data availability and reliability).

APPLICATIONS AND RESULTS

In addition to the open-framework features of SimCLIM, described above, several specific enhancements of the system have been made to deal with local-scale applications of risk assessment and evaluation of adaptation options. One set of developments were made for adaptation to changing risks from tropical cyclones in the Cook Islands. Another new development involves a linkage between SimCLIM and Danish Hydraulic Institute (DHI) models. These developments are described below.

Simulating impacts and adaptation to tropical cyclone risks, Cook Islands. New SimCLIM simulation tools were developed and implemented for a case study of tropical cyclone flooding for the community of Avatiu on the island of Rarotonga, Cook Islands (**Figure 2**), conducted as part of an Asian Development Bank study (ADB, 2005). The island of Rarotonga has a long history of dealing with tropical cyclones. For example, the storm surge (including wave run-up as well as barometric effects and wind and wave set-up) from Cyclone Sally in 1987, estimated to be about a 1-in-13 year event, caused extensive damage to the port of Avatiu and overtopped the beach ridge along that segment of coast, causing considerable damage to residential and commercial structures and infrastructure equivalent to 66% of Cook Islands GDP (Kirk and Dorrell, 1992). A spate of tropical cyclones over the period 2003-2005 has heightened awareness of the risks. The continuation of development on the exposed coastal strip has increased vulnerability. Climate change is threatening to exacerbate the risks. Sea-level rise will add to the storm surge height and the intensity of severe tropical cyclones may increase with global warming (Henderson-Sellers *et al.*, 1998; IPCC, 2007).

To assess the risks, the Avatiu area was modelled within the open-framework SimCLIM at a spatial resolution of 5m and populated with elevation data and vector files of residential and commercial structures, roads, streams, and the like. For simulating flooding events, a simple reduced-form coastal flood model was developed based on outputs from engineering studies for Avatiu that used complex wave models, storm surge models, and the like (e.g., JICA, 1994; Kirk and Dorrell, 1992). A chain of relationships – from wind speed, wave height to total water run-up elevation and their associated return periods – was developed and related to the potential wave overtopping of the beach ridge. The overtopping height is the difference between total run-up elevation and the height of the beach ridge or protection structure at a site. After overtopping, the water is distributed over the study area using a simple distance-decay function calibrated on the areal extent and depth of flooding during Cyclone Sally. New SimCLIM developments were required to assess future impacts and damages, including: a "transient" (e.g. year-by-year) mode of simulation; a sea-level scenario generator; functions for assessing adaptation options; and economic tools for evaluating impacts and the benefits and costs of adaptation options (**Figure 2, right panel)**.

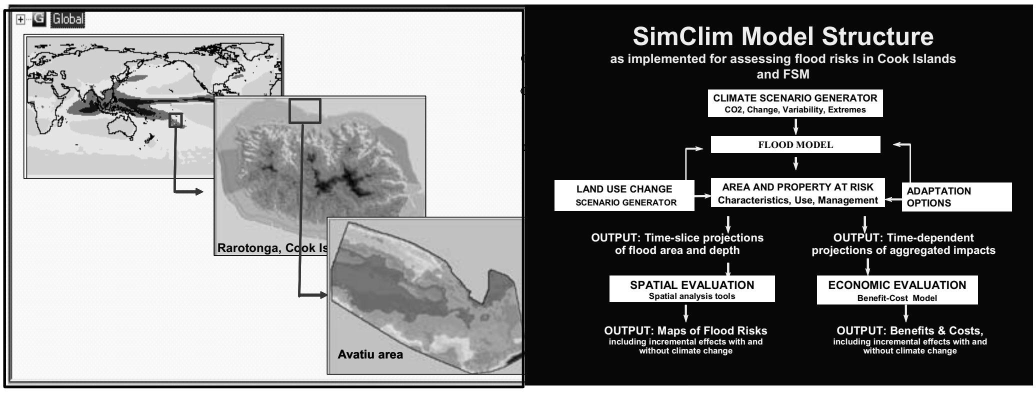


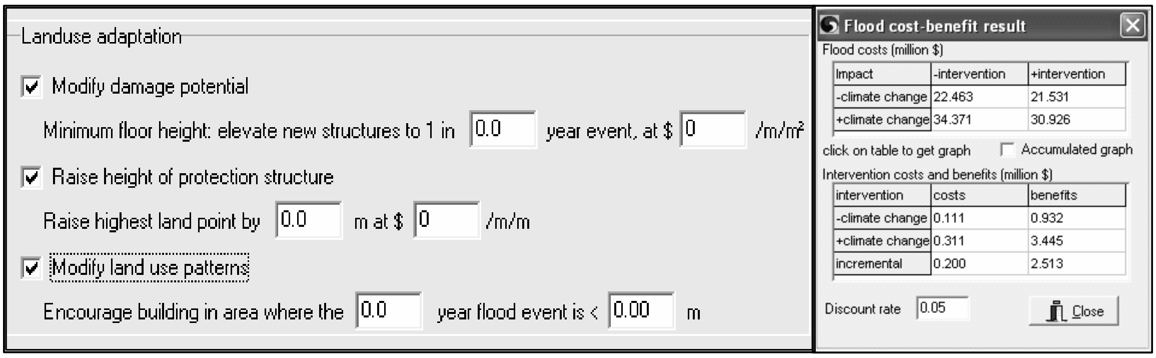
Figure 2: Left panel: multi-scale datasets within SimCLIM, from global to the case study community of Avatiu on the island Rarotonga, Cook Islands. Right panel: additions to SimCLIM that provide the capacity for both spatial "time-slice" and time-dependent projections of impacts, adaptation and economic impacts of coastal flooding from tropical cyclones.

A **"**transient**"** (time-dependent) mode of simulation was developed for economic evaluation of impacts and adaptation options. The economic evaluator requires simulations of floods in time-steps (e.g. yearly) and for the range of flood frequencies at each step as climate changes. For each building type, functions were developed that relate flood heights to dollar damages (i.e. "stage-damage" curves). At each time step, the expected damages are summed over the range of return period floods. The yearly simulated damages are discounted and aggregated to give an annualised expected damage, in present dollar value. This provides a basis for comparing the benefits of adaptation options (i.e. damages prevented) with their costs -- benefit-cost analysis.

A sea-level scenario generator was developed for SimCLIM (Warrick et al., 2005) that takes account of regional variations in the rate of sea-level rise as projected by GCMs as well as local non-climate-change related trends (e.g. from vertical land movements). In terms of changes in cyclone intensity, SimCLIM also uses a simple scaling technique related to global-mean temperature change: a range of 2.5% to 10% increase in cyclone intensity per degree of warming (based on Henderson-Sellers, 1998; Giorgi and Hewitson, 2001).

Functions were developed for examining three adaptation options for the Avatiu community: (1) raising the minimum floor heights of new structures built in the hazard zone; (2) constructing a protective sea-wall; and (3) modifying land use over time to avoid the most hazardous areas. The SimCLIM user specifies the design and enters the additional unit cost that is entailed in meeting the requirement, as shown in **Figure 3 (left panel).** These adaptation options can be run individually or in combination. Importantly, multiple simulations with and without climate change, and with and without adaptation, provide a basis for identifying the incremental benefits and costs associated specifically with climate change (as compared to natural climate variability).

An example of the output from SimCLIM is shown in **Figure 3 (right panel)**. This particular simulation used a sea-level rise scenario of 25 cm and a change in cyclone intensity 15% by the year 2050. The adaptation (i.e. "intervention") option chosen was the raising of floor heights on new structures built to the 1-in-25 year flood height, at a nominal cost of \$100 per m/m^2. The top half of Figure 3 (right panel) shows simulated flood damages. It can be seen that climate change in the absence of adaptation (-intervention) increases damages considerably, by about 50% (from \$34.4m to \$22.5m). With adaptation, raising floor heights (+intervention) is effective in reducing damages -- with or without climate change. The bottom half of Figure 3 (right panel) compares the benefits (damages prevented) with the costs of adaptation (discounted at 5% and summed to present). In this example, the benefit of raising floor heights in the absence of climate change is \$0.9m (i.e. \$22.4m-\$21.5m), which compares favourably to a cost of \$0.1m. With climate change, the benefits are even greater, \$3.4m, as compared to a cost of \$0.3m. In other words, the benefits of raising floor heights exceed their costs, with and without climate change – a "no regrets" option. Finally, the output in the lower half of Figure 3 (right panel) also shows the *incremental costs and benefits* of adaptation. These are the adaptation costs and benefits associated solely with climate change after subtracting the effects from natural variability. In this example, the incremental benefits of raising floor heights are \$2.5m as compared to the incremental costs of \$0.2m.



Landuse adaptation

☑ Modify damage potential

Minimum floor height: elevate new structures to 1 in 0.0 year event, at \$ 0 /m/m²

☑ Raise height of protection structure

Raise highest land point by 0.0 m at \$ 0 /m/m

☑ Modify land use patterns

Encourage building in area where the 0.0 year flood event is < 0.00 m

Flood cost-benefit result

Flood costs (million \$)

Impact	-intervention	+intervention
-climate change	22.463	21.531
+climate change	34.371	30.926

click on table to get graph ☐ Accumulated graph

Intervention costs and benefits (million \$)

intervention	costs	benefits
-climate change	0.111	0.932
+climate change	0.311	3.445
incremental	0.200	2.513

Discount rate 0.05

Figure 3: Left panel: the SimCLIM user interface for assessment adaptation options for reducing risks from coastal flooding in the Cook Islands. Right panel: an example of output for assessing flood damages and the benefits and costs of adaptation (raising minimum floor heights, in this case).

Using DHI Software Tools to Simulate The Effects Of Climate Change. The Danish Hydraulic Institute (DHI) is one of the world's leading providers of software tools for simulating the quantity and quality of water and its movement. DHI has recognized the need to incorporate tools to allow practitioners of DHI's software to model the impact of climate change. For this purpose, a "DHI-compatible" version of SimCLIM has been developed that provides a seamless link with the suite of Danish Hydraulic Institute models and allows hydrologic analyses to easily be performed under future scenarios of climate change (DHI, 2006). As shown in **Figure 4**, SimCLIM's scenario generator is used to perturb input time-series data (e.g., precipitation, temperature, sea-surface level and wind speed) for DHI's simulation tools, which can easily and efficiently be re-run to examine the effects of changes in climate on model output. This capability allows a large number of questions relating to the impact of climate change on water quantity and quality to be addressed quickly, for example: What are the possible changes in future risks of flooding? How might the reliability of water supply be affected in the future? What is the potential change in coastline over the coming decades? What is the potential impact on water quality and ecology of wetlands?

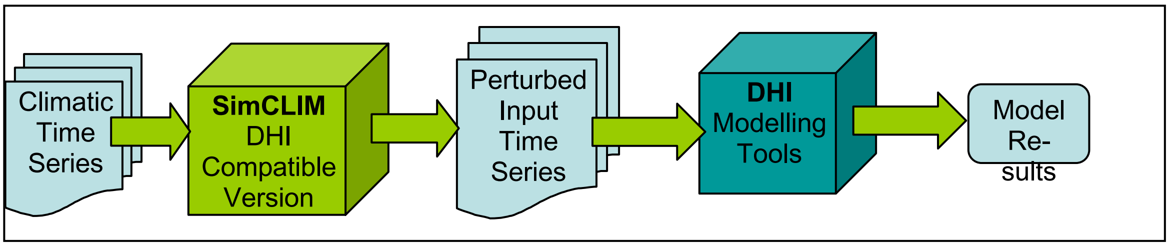


Figure 4: Process for simulating the impact of climate change using SimCLIM and DHI modelling tools.

To illustrate, **Figure 5 (left panel)** shows an example of a rainfall time series perturbed by SimCLIM for the Awaroa catchment in New Zealand. The base data is a 100-year average return interval design rainfall event based on Auckland Regional Council design rainfall profile. The climate change scenario selected by the user was: GCM: HadCM3, Year: 2050, Emission Projection: IPCC SRES A2, Climate Sensitivity: High. These rainfall time series were fed into a MIKE 11 model (DHI's 1D channel modeling tool) of the current storm water drainage network for the catchment. **Figure 5 (right panel)** shows resulting discharge hydrographs at the outlet of the model. It can be seen that the peak discharge increases by more than 25%. This is valuable information that can be used when upgrades to the network are planned.

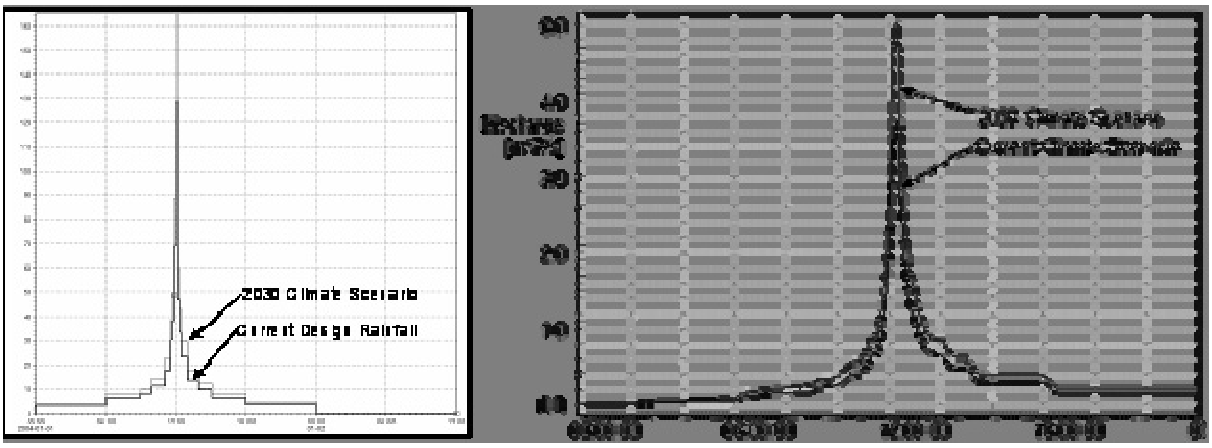


Figure 5: Application of linked SimCLIM-DHI tools to Awaroa Catchment, New Zealand. Left panel: rainfall hyetograph for current climate and a climate change scenario. Right panel: simulated discharge from urban storm water network of current climate and a climate change scenario.

CONCLUSIONS

This paper has presented an overview of the SimCLIM model system and some important new features that increase the capacity for conducting analyses of changes in risk resulting from climate change and of adaptation options for reducing them. In general, this kind of risk-based approach to adaptation, which blends natural climate variability with climate change, and which blends global and regional changes with local impacts and response, is consistent with recent efforts to find ways of merging conventional "top-down" and hazard-based "bottom-up" approaches to adaptation assessment (Warrick, 2006). The overall aim of such assessments is to promote a long-term process of "climate-proofing" development, whether in developed or developing countries. The recent expansion of the SimCLIM model system, including its linkage with DHI models, is designed to provide valuable tools to assist in this climate-proofing process.

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A rainfall-runoff model´s sensitivity to extreme events

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Keywords: rainfall-runoff model, climate, sensitivity, response surface

ABSTRACT

Extreme weather events can cause great damage to society and also endanger human health. A climate change could lead to an increased frequency of such extreme events and recent years have driven research within this field. There are difficulties in assessing the probability of increases in extremes, such as the inherently low number of observations and the poor representation of extremes in global climate models. This paper describes a methodology to model extreme events in a probabilistic way through sensitivity surfaces combined with output from a number of regional climate models. Sensitivity surfaces are probabilistic diagrams of reaching threshold values in a perturbed climate. They were created by running a model with differentiated changes in the observed input data (e. g. temperature and precipitation). The probability for reaching an *a priori* determined threshold any given year was then calculated from the results and plotted as contour lines. Climate projections from large-scale models could then be projected onto the sensitivity surface, producing a probability estimate of a given situation. An underlying assumption is that the intra-annual variation in the modeled variables is similar for the models, or that the threshold is insensitive to intra-annual variations. In this study the impact model was a hydrological model (HBV) run for four areas; Lake Vänern, Lake Mälaren and Lule River in Sweden, and the runoff from the entire Baltic Sea basin. A threshold can be set generally, such as the probability of reaching the 50-year return period, or be more site-specific, relating to past observed events. These specific thresholds relate to events which are possibly harmful. Preliminary result indicated that Lake Mälaren was most sensitive to differences in the intra-annual variations of the driving variables. Increased water temperatures were not compensated by increased precipitation concerning low water levels. The results for Lake Vänern indicated that only a slight increase in precipitation increased the probability of reaching critical water levels in the lake, thus forcing a maximum outflow for a long time period. The results can be used as decision support system to minimize the risks for future damage to societies and human health.

INTRODUCTION

Projections of climate scenarios on global climate models have large differences because of uncertainties in both climate models and scenarios. Further uncertainties are introduced when local impact models are used in climate scenario risk assessments coupled to global models. How to combine these uncertainties in a probabilistic manner to give stakeholders and decision-makers useful information about future risks is a challenging task. Basically, there are two approaches used in local impact modelling; top-down or bottom-up approach. The latter approach can be done in a probabilistic “Risk-based” manner, making it three approaches (Carter and Fronzek, 2005). The first approach is a direct approach, where outputs of climate projections are fed into impact models and the effects of a climate change are evaluated *a posteriori*. The inverse approach identifies thresholds *a priori* in the impact model by a sensitivity analysis (Jones, 2001). Climate projections are then projected onto the response surface of the sensitivity analysis. Both approaches should ideally be conducted with a number of impact as well as climate models. In the probabilistic approach likelihoods are given to each scenario projection, thus creating a probabilistic future climate. All these approaches are conducted within the EU project ENSEMBLES (ENSEMBLES, 2007). This paper deals with the methodology of creating response surfaces for a rainfall-runoff model.

METHODS

The work presented in this paper concentrated on the methodology around the probabilistic approach with three Swedish drainage basins (Lake Vänern and Lake Mälaren) as test areas, as well as a simplified model for the Baltic Sea drainage basin. The two Swedish basins are both dominated by large lakes and include densely populated areas, while the latter is a scarcely populated northern basin that is important for hydropower production. The sensitivity analysis was carried out with the hydrological HBV model. Although it was originally developed as rainfall-runoff model it is now used in many different applications, including climate studies, (Bergström *et al.*, 2001).

Impact thresholds were selected for the model output as a first step of the sensitivity analysis. These thresholds represent either specific historical critical events or unwanted conditions. In Sweden typical critical situations are high levels in the water power plant dams, large spring floods or long-lasting low-water levels. If no clear thresholds could be identified, the observed accumulated flow over a time period or the return period of a high flow was be used. For Lake Vänern the threshold was set to "200 consecutive days with outflow equal to or above 1000 m^3s^{-1}". This particular situation occurred during the winter 2000-2001, causing extensive damage to surrounding communities and risk of a dam break, which would have been catastrophic for the heavy populated area along downstreams Göta River. The drainage area has a regulation today, but sensitivity surfaces were also created for a situation with a proposed regulation which would allow a higher release before critical levels are reached, thus avoiding some of the situations with high water levels.

The threshold for Lake Mälaren was set to "50 consecutive days with water levels equal to or below 4.15 m." This height refers to a critical level in the local elevation reference system for Lake Mälaren where navigation becomes difficult and the intake of water for local water supply can be inhibited. This level also represents a higher risk for saltwater intrusion from the Baltic Sea. Thresholds for the Lule River and Baltic Sea basins were accumulated flows for 30-days and 90-days respectively compared to today's situation. For all basins changes in mean and seasonal runoff have also been analysed.

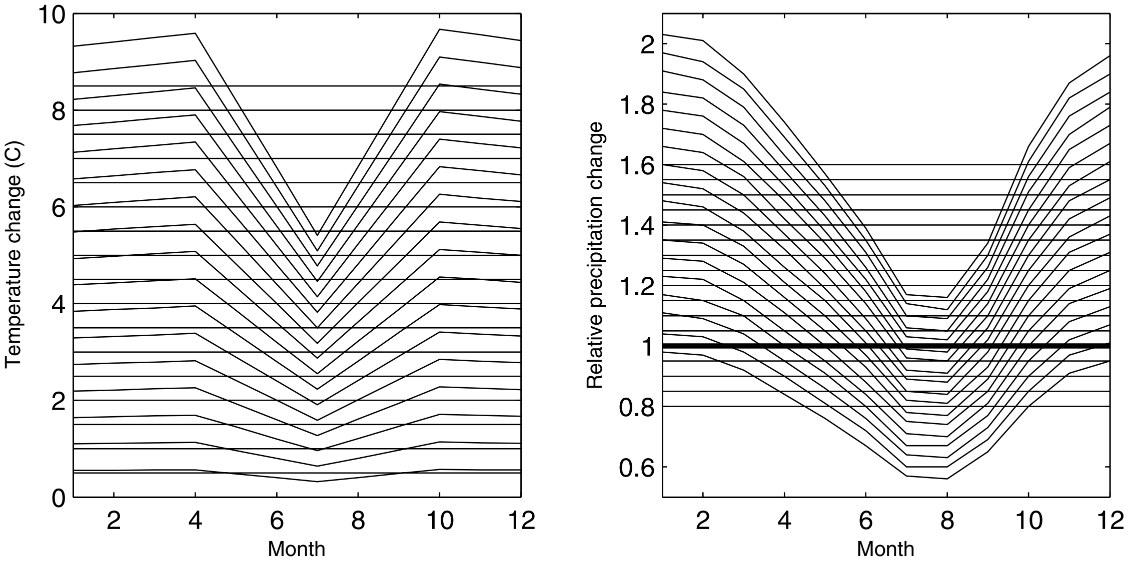
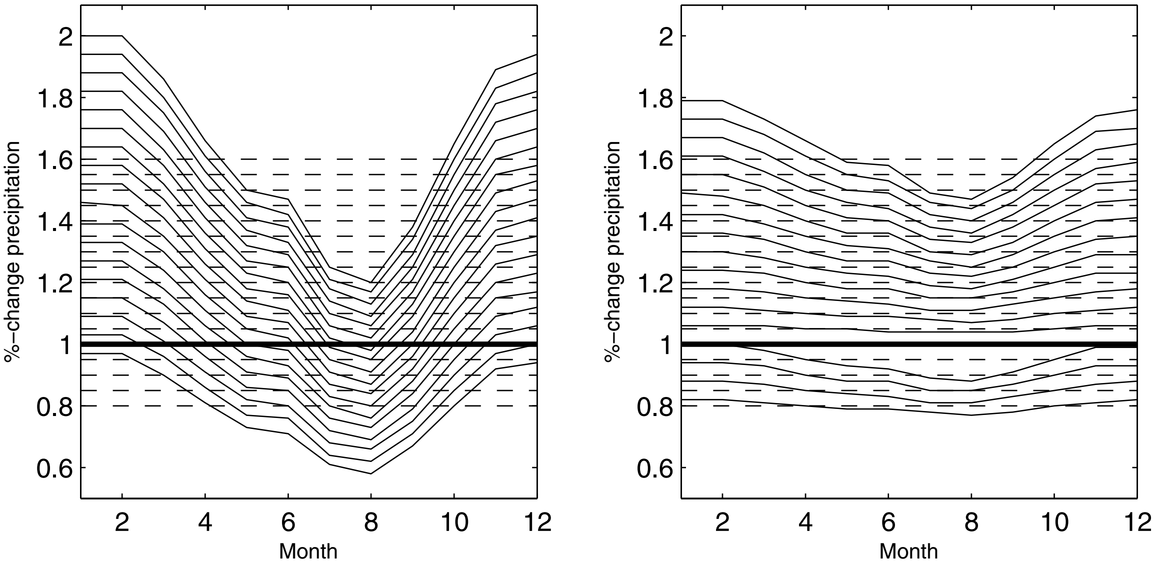


Figure 1. Monthly change factors used to represent seasonal changes for a) temperature and b) precipitation for the Lake Vänern basin. Also shown are the corresponding constant annual change factors (horizontal lines).

Intra-annual variability of both temperature and precipitation are important factors for hydrological regimes. Previous studies, e.g. Prudence Project (Christensen *et al.*2007), have shown considerable monthly variation in projected climate changes, particularly in Northern Europe. For these reasons, it is not sufficient to look only at annual changes of temperature and precipitation. The monthly changes were calculated as a mean value of four regional climate projections, the SRES-A2 and B2 emission scenarios with boundary conditions from the global climate models HadAM3H and ECHAM4 (Räisänen et al., 2004). These simulations represent a changed climate for the period 2071-2100, as compared to a control climate for the period 1961-1990 (Fig. 1). The response surfaces were calculated with changes that were constant throughout the year to varying monthly changes in both temperature and precipitation, resulting in four different combinations to assess the sensitivity of response to such inputs.



a) b)

Figure 2. Two different approaches for representing monthly changes for precipitation for the Lake Mälaren basin. a) Method 1 uses the similar distribution regardless of the magnitude of annual change. b) Method 2 uses a gradually increasing range of distribution with increasing annual change.

Recognizing that the distribution of monthly change is also related to the magnitude of annual change, an additional method for introducing seasonal changes was also tested. In this case, the identified monthly change factors as described above were adjusted according to the amount of annual change (Fig 2). Here, the range of monthly changes gradually increases as annual changes increase (or decrease). This method was only tested in the Lake Mälaren basin, resulting in two additional combinations of precipitation and temperature changes for this basin. The main reason for using this approach in Lake Mälaren was that the results from earlier scenario runs indicated less precipitation in summer and more during winter than observed.

RESULTS

In general, increasing precipitation tends to increase runoff while increasing temperature tends to dampen runoff, as evapotranspiration also increases. The rate of runoff change is therefore highly dependant on the location of the watershed in relation to the current climate and how future climate is projected to change. Basin size and characteristics, such as lake surface area, are also important. Different basins also respond differently to seasonal changes. For example, the northern Lule River basin, where evapotranspiration rates are relatively low, is more affected by precipitation change than temperature change. Furthermore, the Lake Mälaren basin is more sensitive to change than the much larger Lake Vänern basin. There is hardly any difference in the results according to seasonality change of the patterns in Lake Vänern (Fig 3). Regarding maximum discharge however, there is a difference in response according to seasonality. The proposed regulation scheme for Lake Vänern would dampen the risk of high lows. Also with seasonality in the regulation scheme there was a slight reduction of the probability of exceeding this threshold. Winter flows are expected to increase for increased temperature, even with little or no increase in precipitation, which is expected because of an earlier spring flood.

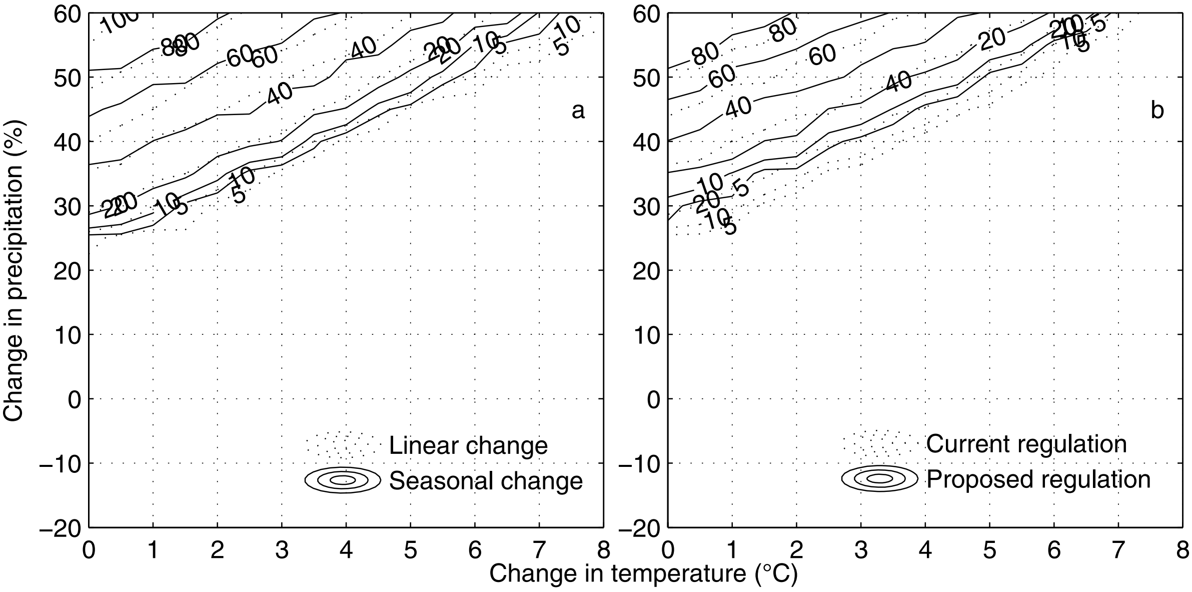


Figure 3. Threshold probability (%) for reaching or exceeding 200 consecutive days with lake outflow equal to or above 1000 m^3s^{-1} for Lake Vänern. a) Current regulation scheme; shown in bold is the response surface using seasonal changes, dotted lines show annual changes. b) Effects from proposed changes to the regulation scheme; shown in bold are results with the current regulation scheme, and dotted are results using proposed modifications to the regulation scheme.

The response surfaces for the Lake Mälaren basin are more sensitive to representation of seasonal changes than those for Lake Vänern, even for annual runoff (Fig. 4a). Changing the seasonality does not affect the results very much.

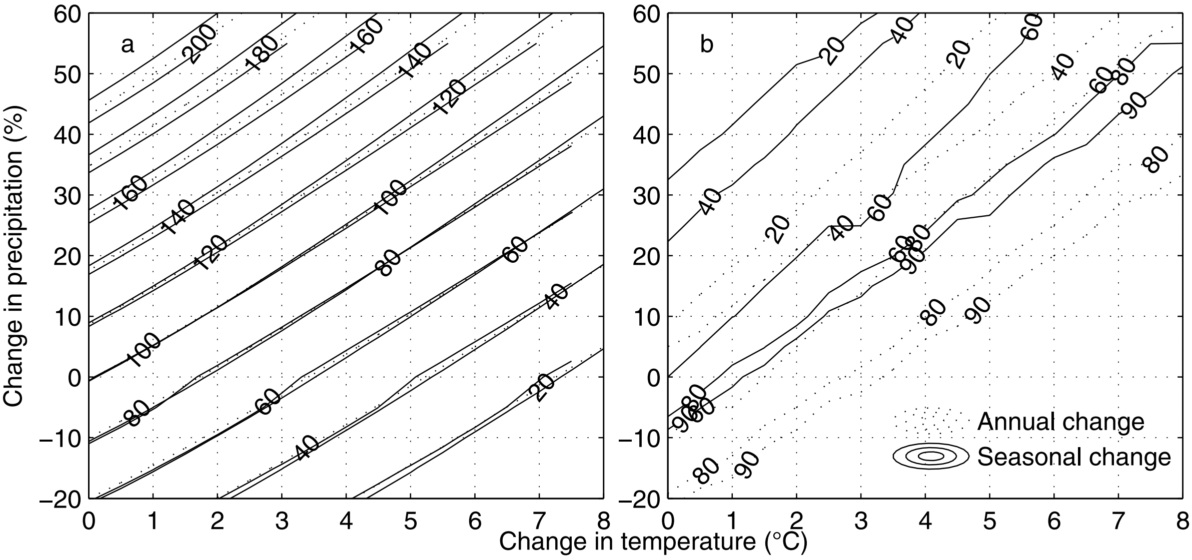


Figure 4. a. Monthly changes in runoff. Dotted lines represent annual change, filled lines seasonal change. b, Same figure as in a, but for the probability of exceeding the threshold.

Although there is already risk for low water levels in today's climate, this increases considerably with a changing climate (Figure 4a). According to the previous climate model simulations, precipitation was projected to decrease during summer months. This makes this basin particularly sensitive to how seasonal precipitation changes are represented in creating response surfaces. Figure 4b corresponds to the seasonality change as it is modelled in Fig. 2a. Using the more moderate change as in Fig. 2b did gave similar results as for the annual change.

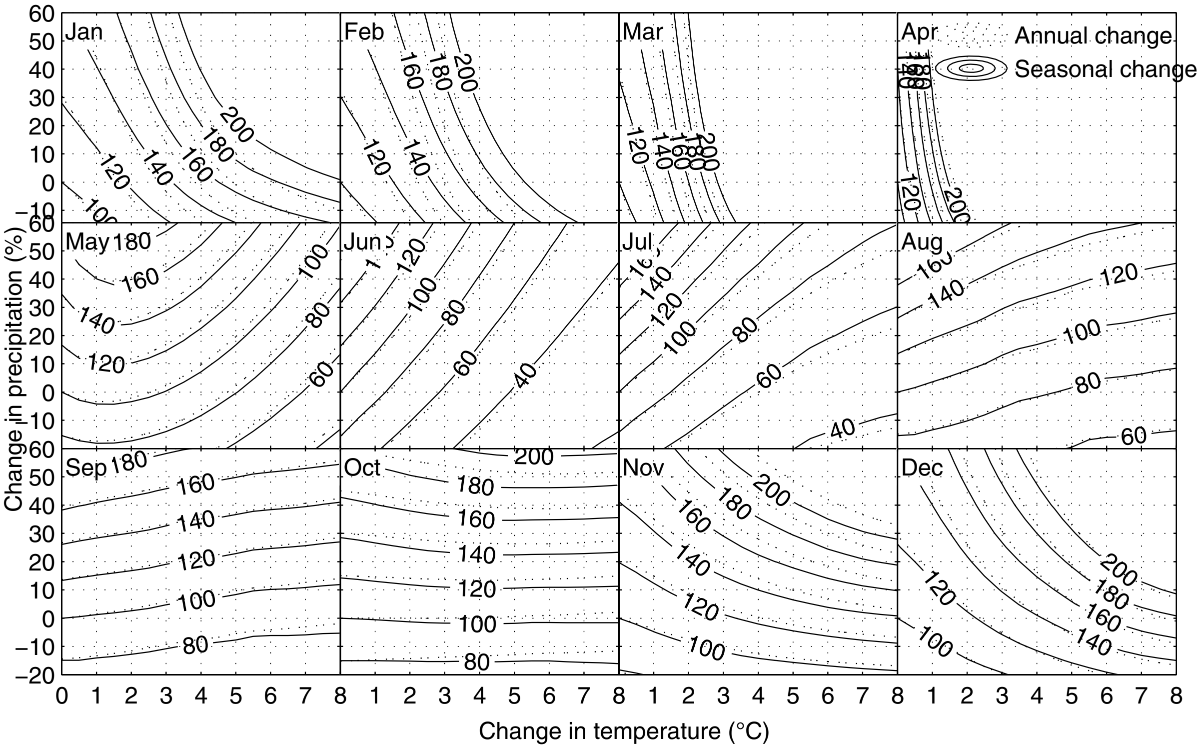


Figure 5. Monthly sensitivity plots for change in flow for the Lule River basin

The annual response surface for Luleå River was quite insensitive to temperature change concerning the amounts of runoff, but the impact of temperature was dramatic on a monthly basis (Fig. 5). The figures basically shows a shift in the timing of the spring flood. Only small differences according to seasonal changes were seen for annual runoff in the Baltic basins (Fig. 6). Seasonal impacts are more pronounced for threshold surfaces than for the annual runoff.

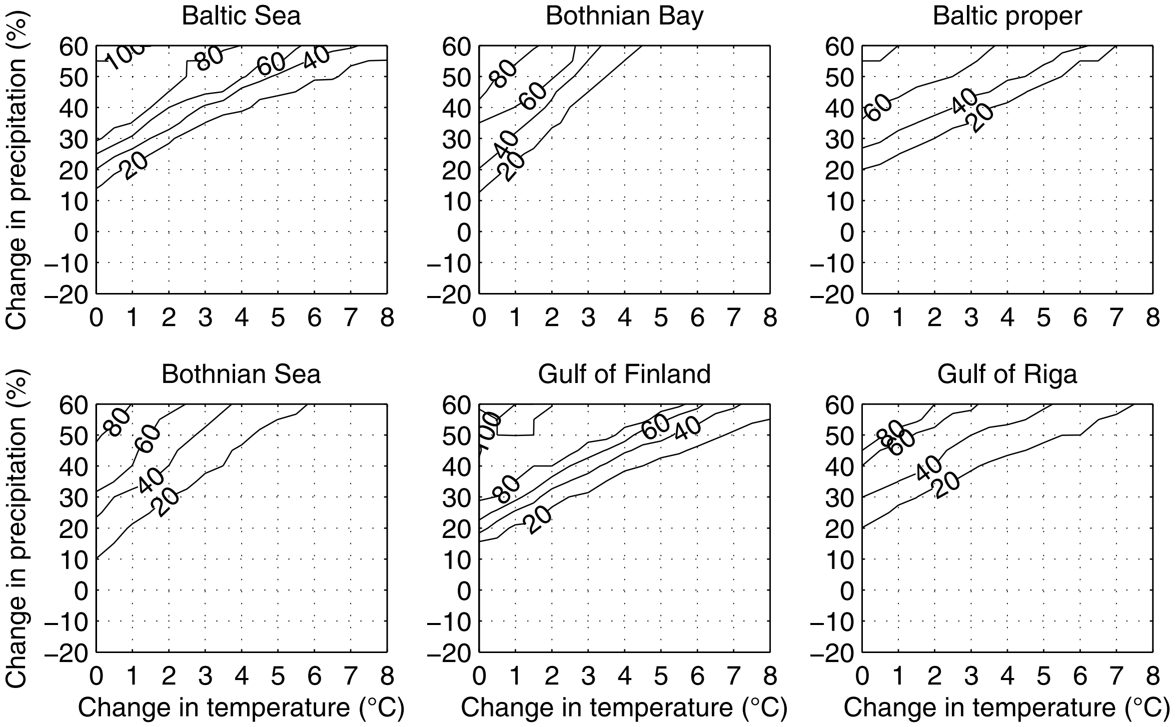


Figure 6. Threshold probability (%) for reaching or exceeding the observed (1961-1990) maximum value for 90-day accumulated flow for the main drainage basins to the Baltic Sea.

Output from the HadCM3 perturbed physics experiment was overlaid on the response surfaces to evaluate effects of the projected A1B scenario. The data is not probabilistically weighted, so it would represent an analysis of type 2. This example indicated that problems would increase for Lake Vänern, but not dramatically (Fig. 7). The increase in precipitation was compensated by an increase in temperature, which leads to higher lake evaporation.

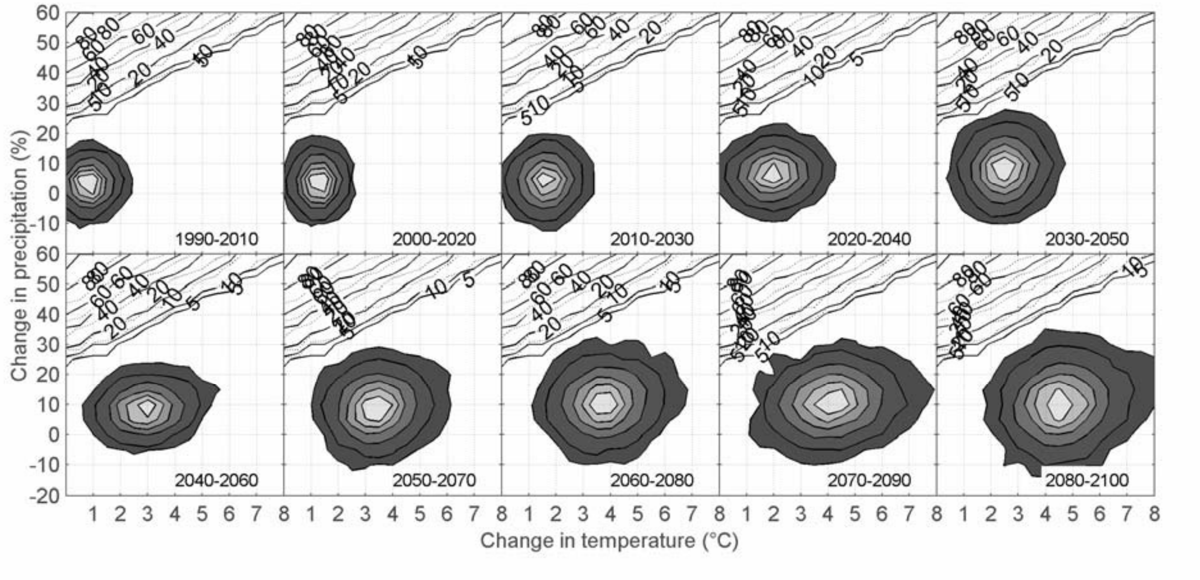


Figure 7. Perturbed Physics experiment overlaid on the response surface for Lake Vänern.

DISCUSSION AND CONCLUSIONS

The response surface for Lake Vänern indicated an increased risk of reaching the threshold in a future climate, but the increase was not dramatic. However, the results are preliminary since the

weighting of the climate scenario projections still needs to be done. The results indicted that the basins responded very differently to seasonality. The HBV model has some problems with too large evaporation with large temperature increases, so the result for the low-water simulations needs further analysis.
Response surfaces are an effective way of visualizing local climate impact modelling. An advantage is the ability to calculate the joint probabilities of a multitude of future climate scenarios in terms of the risk of reaching a predetermined threshold. Much effort has to be put in finding appropriate thresholds for a specific drainage area, since the conditions change from basin to basin. Stakeholders should be able to value the risk assessment if the threshold is a well-known and well defined situation rather than a change in the mean climate. Response surfaces could also be used to assess the possible positive effects of a climate change in terms of for example increased water power production.

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What does Current Agricultural Adaptation to Drought mean for Future Vulnerability?

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Keywords: Canadian droughts, water resource management, impacts and adaptations, vulnerability

ABSTRACT

The 2001 to 2002 drought was one of the first coast-to-coast droughts in Canada, and was one of the worst droughts to occur since the 1930s. Intense dry conditions extended into major agricultural regions from the western province of British Columbia into the Prairie Provinces, and also affected the normally temperate Great Lakes-St. Lawrence region and four Atlantic Provinces. The 2001 and 2002 drought caused over $3.6 billion in direct agricultural production losses. Agricultural activities and water resources were negatively impacted. Adaptations used to deal with the drought were costly and several were limited in their effectiveness.

The climate change adaptation literature often assumes perfect adaptation will occur, with farmers and water resource managers knowing exactly how to take advantage of information. In reality, many adaptation measures are recommended, but implementation of these measures are constrained by factors such as finances, knowledge, technology, and personal preferences. Very little research has been done in Canada and other countries to document and evaluate the effectiveness of actual adaptation options implemented by the agricultural and water resource sectors. Multi-year droughts are especially difficult to deal with as they require much more awareness, resources, capability and innovation than single year droughts. They can also cause impacts in non-farm sectors, and result in longer, more difficult recoveries. The effectiveness of adaptation measures needs to be evaluated to improve adaptation to future severe droughts. Such evaluations also allow us to estimate actual adaptive capacity and to help improve modeling of future adaptation.

Our Agricultural Drought Adaptation (ADA) project helps to address these vital information gaps. The purpose of this project is to improve the understanding of current adaptation processes and options used in Canadian agriculture. Adaptive measures and options used during the 2001 and 2002 drought are documented and compared using several methods. This approach enabled us to compare adaptation in different agricultural regions. We also explore the effectiveness of adaptation by examining criteria such as residual negative impacts, positive impacts, opportunities and barriers, maladaptations, efficiencies and innovations.

We also link ADA with other relevant projects, including the Canada Drought Research Initiative (DRI) and the Institutional Adaptation to Climate Change (IACC). Canada DRI seeks to better understand the physical characteristics of and processes influencing Canadian Prairie droughts, and to contribute to their better prediction, through a focus on the severe drought of 1999 to 2004/5. The goal of the IACC project is to develop a systematic and comprehensive understanding of the capacities of regional institutions to formulate and implement strategies of adaptation to climate change risks and the forecasted impacts of climate change on the supply and management of water resources.

INTRODUCTION, PURPOSE AND METHODS

The drought of 2001 to 2002 (nick-named the Ada drought) can be considered one of the worst natural disasters in Canada. Consequently, the Ada drought offers a unique and timely opportunity to improve our understanding of current adaptation processes and options in Canadian agriculture, especially with regard to drought. We use the record to near-record drought of 2001 and 2002 as the basis for improving the understanding of adaptation. We also use that drought as a harbinger of possible future climate change stresses.

The Ada drought was one of the first coast-to-coast droughts in Canada, and was one of the worst droughts to occur since the 1930s. Intense dry conditions extended into major agricultural regions from the western province of British Columbia into the Prairie Provinces, and also affected the normally temperate Great Lakes-St. Lawrence region and four Atlantic Provinces. During 2001 and 2002, the Canadian Gross Domestic Product fell some $5.8 billion with the larger loss in 2002 at more than $3.6 billion. Employment losses exceeded 41,000 jobs during the two-year period. Drought also contributed to a negative or zero net farm income for several provinces for the first time in 25 years with agricultural production over Canada dropping an estimated $3.6 billion in 2001 to 2002. Previously reliable water supplies such as streams, wetlands, dugouts, reservoirs, and groundwater were placed under stress and often failed (Wheaton et al. 2005).

This paper discusses the Agricultural Drought Adaptation Project (ADA) (Wheaton et al. 2007) which is the first work to comprehensively assess the severity, area, and duration of past droughts across the entire country. It is also the first work to estimate the characteristics of future droughts across Canada. It is also the first to extensively document and categorize current adaptations and the dynamics of adaptation to drought across Canada. The project was designed to provide many benefits, such as improved information to characterize the nature of droughts, as an aid in the development of actions to reduce vulnerability to droughts, and building more effective adaptation.

The purpose of ADA was to improve the understanding of current adaptation processes and options used in Canadian agriculture. Adaptive measures and options used during the 2001 and 2002 drought are documented and compared using several methods. This approach enabled us to compare adaptation in different agricultural regions.

The methods included literature reviews, searches of media (e.g. newspapers and newsletters), research framework development and application, and use of criteria to improve understanding of adaptation effectiveness. A chronological description of the adaptations recommended and used was developed. Examples of adaptation strategies for short and longer periods were provided.

DROUGHT CHARACTERISTICS

Two types of drought assessment demonstrated that the 2001 to 2002 drought , i.e. Ada, was the most severe drought for several decades in southern Canada. However, the spatial extent and severity of droughts during much earlier droughts, that is, those of the 1920s and 1930s, were found to be more extreme. However, at several individual stations, Ada was the worst drought during the period, 1915 to 2002, at individual stations. Most of these stations were in the Prairie Provinces (i.e. Alberta, Saskatchewan and Manitoba).

Ada was also a rare cross-Canada extreme drought. An important difference for 2001 when compared with the other severe drought years is that interior British Columbia, the Prairie Provinces, southern Ontario, Quebec and Atlantic Canada all experienced dry conditions simultaneously. In the 105 years analyzed, only the summer of 1914 had coincident droughts of the same magnitude in all areas as did 2001. Furthermore, areas less accustomed to droughts were also affected including the northern agricultural Prairies and Atlantic Canada. Impacts were greater since these recent droughts followed a relatively wet period in the 1990s, thus making the contrast more noticeable. Both these factors of large area covered and lack of recent experience with drought combined to make adaptation more difficult. Future droughts were projected to dramatically increase in both spatial extent and severity, if the effect of temperature is considered. Climate change scenarios indicate that the worst droughts on record, including the Ada drought, may be frequently exceeded.

DROUGHT ADAPTATION ASSESSMENT

Appropriate adaptation is difficult and constrained by many barriers. It is a challenge for managers such as farmers and water resource managers to know how to take most advantage of information. Adaptation measures may be recommended, but implementation of these measures is limited by factors such as finances, knowledge, technology, and personal preferences. Very little research has been done in Canada and other countries to document and evaluate the effectiveness of actual adaptation options implemented by the agricultural and water resource sectors. Multi-year droughts are especially difficult to deal with as they require much more awareness, resources, capability and innovation than single year droughts. They can also cause impacts in non-farm sectors, and result in longer, more difficult recoveries. In order to improve adaptation to future severe droughts, the effectiveness of adaptation options needs to be evaluated and improved. This is required to estimate actual adaptive capacity and to help improve modelling of future adaptation. This section describes the framework that we developed and applied, then gives results for the media survey, and a discussion of adaptation effectiveness including recommended versus applied adaptation options.

Newspapers are often overlooked as information sources for drought impact and adaptation assessment. The assumption behind the survey of print media is that the media reflect what is happening and being discussed in the regions and the country. We used the print media to explore several questions, including: “what types of adaptations options are being discussed (both recommended and used); what are the spatial and temporal patterns of the adaptation discussions; and what types of adaptation options are the most popular (i.e. mentioned most frequently).

The framework Wittrock and Wheaton (2007) used to organize the media survey results for the Prairie Provinces has two main parts. The main topics are “crops, livestock and water.” These were selected as they are commonly mentioned topic areas in the media and help address the question: what sectors requires adaptation? Each of main topics has sub-topics including: technological developments, government and community programs, farm production practices and farm financial management. These topics address the “how” of the adaptation process. The media survey was demonstrated to be an effective method to examine several characteristics of the adaptation process over several years and several provinces.

The media survey of 1999 to 2006 for the Prairie Provinces resulted in the development of a database of about 853 articles regarding adaptation to drought. The total number of articles of this period was highest in August 2002, reflecting a peak of concern regarding the drought and actions to manage impacts (Figure 1). The number of articles increased quickly to this peak, but the number declined much more slowly after 2002 indicating a continued sensitivity to the need for continued adaptation. The lowest numbers were for 1999 and 2006, the tail ends of the period. This frequency pattern was consistent when examined for each Prairie Province, except that the numbers did not decrease as rapidly after 2002 for Saskatchewan as compared with the other provinces. A monthly analysis of the numbers of articles shows that spring and late summer to early fall are peak times of adaptation concerns. This pattern likely corresponds to seeding and harvesting times for crops, for example. A provincial check of these numbers shows that Manitoba has the lowest number of articles. Therefore, it appears that Manitoba has less concern for adaptation to drought. Manitoba was less affected by the drought, so this finding is expected.

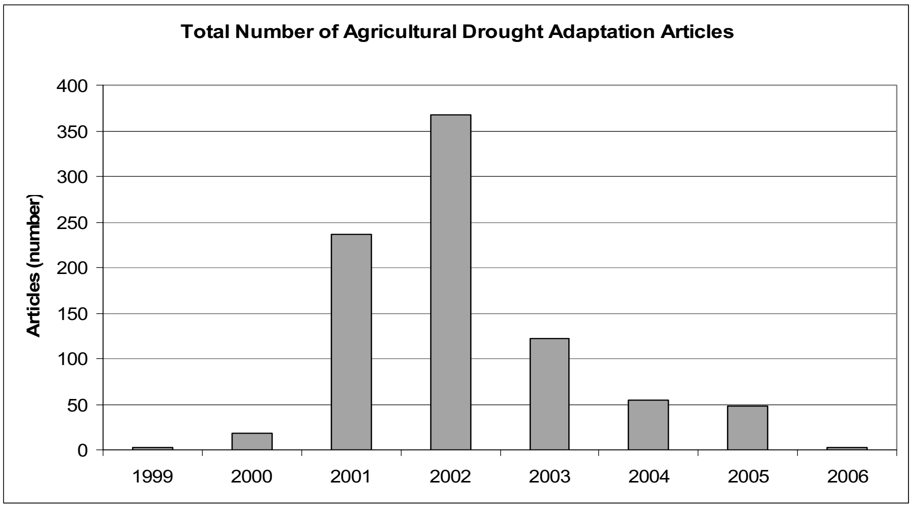

Figure 1 Annual Number of Agricultural Drought Adaptation Media Articles (Prairie Provinces, 1999-2006)

In Eastern Canada, the total number of drought articles peaked dramatically in August 2001, a year earlier than for the Prairie Provinces (Figure 2). In Atlantic Canada, most citations of drought adaptations occurred in 2001 during the peak drought period and decreased sharply in 2002. In Ontario, the number of articles detailing drought adaptation options was equal for both 2001 and 2002 and highlighted different adaptations used over in the two years.

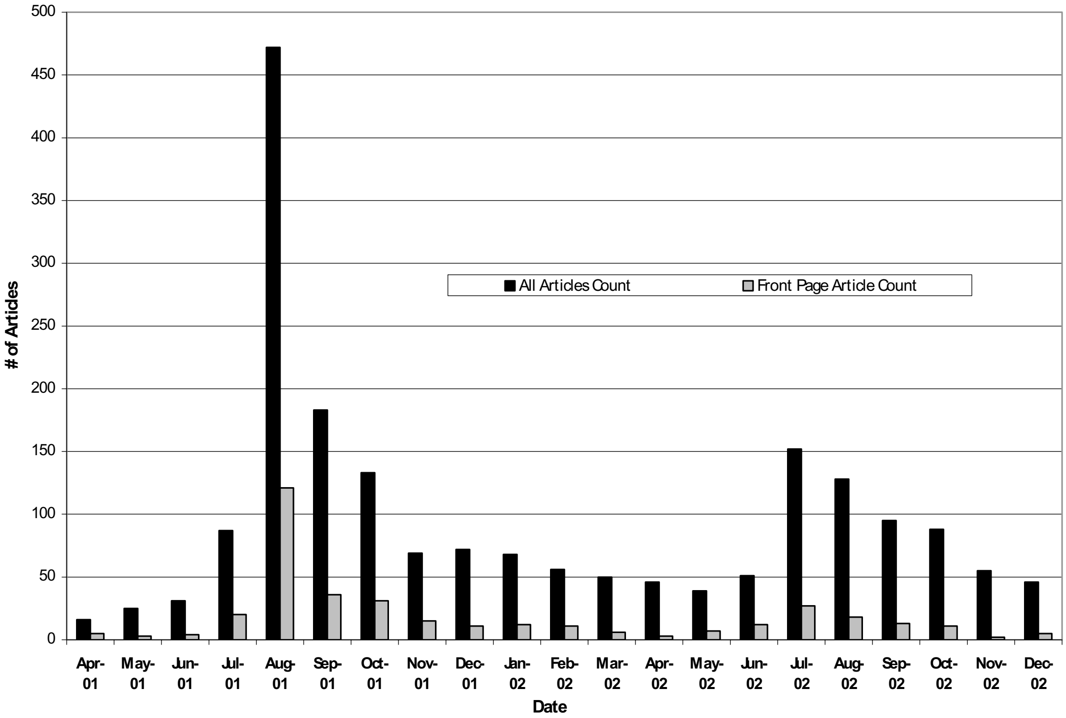

Figure 2 Number of Agricultural Drought Articles (Eastern Canada, 2001-2002)

Drought adaptation topics found using the print media survey have distinctive time and space patterns. In the Prairies, the topics with the greatest number of articles were “crops”, followed closely by “livestock” (Figure 3). The next most frequently mentioned topics were “water” and “economics” with similar totals. The topics of “community support and technology” were second lowest and lowest in frequency. This pattern indicates the areas of the greatest and least adaptation emphasis. The most frequently mentioned topics are not surprises, but it does appear that community support and technology may have much less emphasis than may be expected. This means that such coping measures may be under-utilized and could address some of the adaptation deficit, or the negative impacts that remain after adaptations are applied.

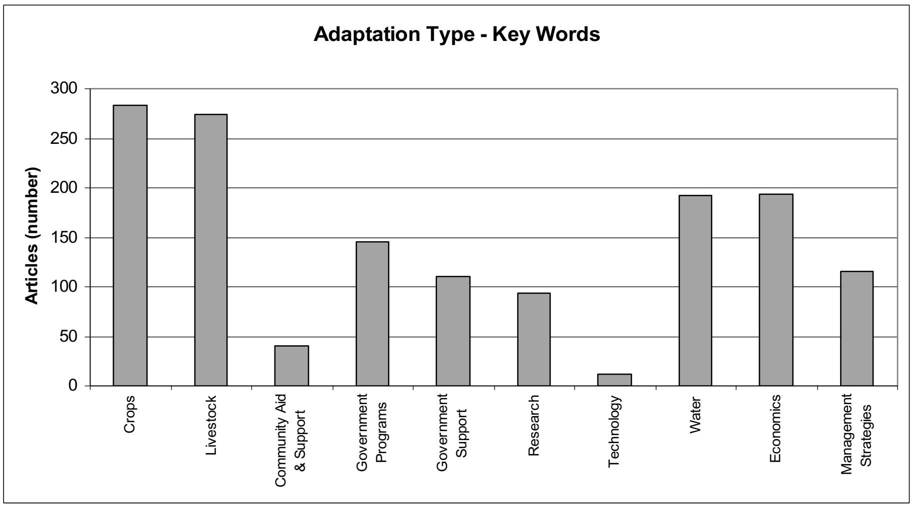

Figure 3 Frequency of Media Articles for Selected Drought Adaptation Topics (Prairie Provinces, 1999-2006)

The pattern of adaptation dynamics changed somewhat within each year and for each province. For example 2001 showed a larger emphasis on water, followed by livestock and crops for all three Prairie Provinces, while in 2002, livestock, then crops and community support were the “top” adaptation options. On a provincial basis, the media survey results show that livestock, then crop and water management strategies were most frequent topics for Alberta. Alternatively, the topics of crops, then livestock and economics were the top concerns for Saskatchewan and Manitoba.

In Eastern Canada, the six most frequently mentioned adaptation options identified as being used during the Ada drought were: irrigation, crop insurance, water conservation and management, Ontario Low Water Response (OLWR)/Water Response Teams (WRT), the Net Income Stabilization Account (NISA) and the Canadian Farm Income Program (CFIP). Many other adaptation options were mentioned, including types in the categories of government assistance, finance, research, health, as well as soils, crops, livestock, and pest management. A lack of awareness of programs to decrease vulnerability was indicated and stresses the need to increase awareness.

Adaptation is most effective if it is implemented properly, facilitated and has few barriers. Barriers to adaptation (to drought) in Canada were documented, including lack of knowledge of water supplies and water use. Barriers to dealing with droughts documented for the Prairie Provinces included lack of funds, lack of research, and difficulty in making changes. Provincial and national drought and integrated water management planning could be useful vehicles for reducing vulnerability to water scarcity. In Eastern Canada, different levels of local leadership and capacity, lack of funds to expand water infrastructure, and lengthy bureaucratic processes to obtain water permits were identified most frequently as barriers to implementing adaptations to lessen vulnerability to drought.

Even if adaptation is applied, it may not be effective. Effectiveness of adaptation is difficult to measure so we described effectiveness using criteria including residual negative impacts, positive impacts, opportunities and barriers, mal-adaptations, efficiencies and innovations. Aspects of effectiveness were described using a literature review and examples from the media survey. For example, innovations were discussed and examples provided in the areas of research regarding drought causes, monitoring of drought, community support, communication, diversification, and livestock management. We concluded with a listing of the stages of an effective process of adaptation.

We also compared recommended adaptation options with the actual options. Many actual adaptations were recommended and implemented, but the opposite also was found. Innovative options were considered to include those that were used, but did not appear as recommendations in the survey. For example, innovative water sharing arrangements were made and carried out, and farming equipment was modified to suit the shorter and sparser crops. For example, reduced/conservation tillage was recommended in order to reduce soil erosion, but more land was left fallow in 2001 to reduce input costs.

Even with the adaptation capacity displayed during the 2001 to 2002 drought in Canada, several negative impacts occurred and impacts and adaptations were costly. This finding indicates that a threshold of adaptive capacity appears to have been reached for this type of drought. This means that adaptation to drought has considerable room for improvement.

We also linked ADA with other relevant projects, including the Canada Drought Research Initiative (DRI) and the Institutional Adaptation to Climate Change (IACC). Canada DRI seeks to better understand the physical characteristics of and processes influencing Canadian Prairie droughts, and to contribute to their better prediction, through a focus on the severe drought of 1999 to 2005. The IACC project intends to develop a systematic and comprehensive understanding of the capacities of regional institutions to formulate and implement strategies of adaptation to climate change risks and the forecasted impacts of climate change on the supply and management of water resources.

CONCLUSION

In conclusion, much new and extremely useful information was documented. An improved understanding of both past and future possible droughts was gained. Many characteristics of adaptation and the processes of adaptation were clarified, including most frequently used options, their effectiveness, and space and time characteristics of the adaptation processes. Canada has relatively abundant water, food, trained people, money, technology, and other resources to lessen its vulnerability to climate change, including extremes. Despite this capacity, the recent drought of 2001 and 2002 had severe and extensive impacts that should lead us to reconsider our understanding of droughts and adaptive capacity to deal with climate extremes, especially severe, multi-year droughts. Findings of this study indicate not only that most regions of Canada experienced the Ada drought, but coping ranges appear to have been exceeded in several cases. This means that much more attention needs to be paid to adaptation research, planning, capacity building and implementation processes.

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Impact of the North Atlantic Oscillation on features of the hydrological regimes in Europe

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ABSTRACT

The article presents the way in which the North Atlantic Oscillation modifies features of the hydrological regimes of European rivers. A river regime is defined here as the type and temporal structure of streamflow in an average hydrological cycle. The elements of the structure include so-called hydrological seasons, which were the instrument for the study of the regime as well as the basis of its characterisation and an assessment of its variability. Hydrological seasons were determined via the grouping of elementary time units of the year (pentads) on the basis of similarity of one of their features - the frequency distribution of the river discharge. The determination of the hydrological seasons was carried out on the basis of sets of 20 years with extremely high and extremely low values of Hurrell's NAO_{DJFM} index. The analysis embraced 150 rivers of Europe flowing in a variety of environmental conditions. Use was made of daily discharge figures from at least 40-year observation periods spanning the years 1901-2000. The changing number, temporal structure and parameters of the hydrological seasons support the conclusion that each NAO stage produces a different impact on the hydrological regimes of European rivers. The article closes with a classification of the rivers under study in terms of differences in the properties of extreme hydrological seasons in the different NAO stages, followed by a spatial analysis of the results obtained. In the classification, use was made of a hierarchical grouping by Ward's method. An analysis of the high- and low-water stages of the rivers in the years with negative and positive values of the NAO index allowed their comparison and the determination of areas with the most variable and most stable parameters of the hydrological seasons.

INTRODUCTION

The conceptions and theories currently developed to account for present-day climate change commonly emphasise their hydrological consequences. The river discharge, treated as an element leaving the catchment's water cycle, is determined by climatic conditions and other environmental features of the catchment as well as human activity in it. Seasonal changes in the discharge are a natural effect of the prevailing climatic conditions, but multi-year variations may suggest global environmental changes. Hence, the river discharge can be their simple indicator. The issues often discussed in works on hydrology are long-term changes in hydroclimatic elements, their tendencies, trends and cyclicity (Peel et al. 2001, Pekarova et al. 2006), as well as stability of the hydrological regime (Arnel 1999, Krasovskaia 1996, Krasovskaia and Gottschalk 2002, Wrzesiński 2004, 2005). Their results are commonly employed in forecasting models defining properties of the hydrological regime under various scenarios of global climate change.

The hydrological regime defines the state and responses of a river system in relation to the catchment's climatic system and physical-geographic characteristics. Deviations of climatic elements from average levels caused by, e.g., changes in the atmospheric circulation modify the streamflow formation conditions, and hence also the characteristics of the river regime. It is controlled by both, precipitation and air temperature, whose magnitudes show a significant dependence on the intensity of zonal circulation. A simple indicator characterising the atmospheric circulation over the north Atlantic is the North Atlantic Oscillation Index (henceforth, NAO). Its significance for the formation of the streamflow has been emphasised by, e.g., Shorthouse and Arnell (1997), Popova and Shmakin (2003), and Rödel (2006). In winter, the discharges of north European rivers are positively correlated with the winter NAO index, and those of Southern Europe are correlated negatively. While in Northern Europe this relation can be accounted for by an increase in precipitation in a positive stage of the NAO and in Southern Europe by its decrease then, in Central and Western Europe the dependence of winter precipitation on the NAO is rather weak. A strong relation does exist, however, between the NAO indices and air temperatures. Temperature controls the magnitude of water loss through evaporation in summer and the development and disappearance of snow cover in winter. In Central Europe during a warm winter (NAO+) snow cover dwindles, hence meltwater floods are rare and carry small discharge volumes. In a negative NAO stage, in turn, winters are severe with a thick snow cover, thus contributing to high and large-volume flood waves (Styszyńska and Tamulewicz 2004, Wrzesiński 2004, 2005).

The observed effect of the atmospheric circulation on climatic conditions, mostly precipitation and temperature, makes also the discharges of European rivers correlated, to a greater or lesser degree, with the winter NAO index. It follows from an analysis of the temporal structure of hydrological phenomena and their variations in a yearly cycle that the varying intensity of zonal circulation can destabilise the hydrological regime as well. The aim of the paper is to present spatial differences in hydrological regime variations of rivers in Europe, mainly extreme phenomena: high- and low-water seasons, brought about by changes in the atmospheric circulation in the North Atlantic sector.

METHODS

The method employed in the article to determine a river regime was one involving the identification of the temporal structure of hydrological phenomena and their variations in a yearly cycle. Its theoretical foundations can be found in Rotnicka (1993) and its applications in, e.g., Gutry-Korycka and Rotnicka (1998), and Wrzesiński (2004, 2005). An important point in the research procedure is distinguishing characteristic stages of the cycle termed hydrological periods or seasons. It consists in the grouping of elementary time units of the hydrological year on the basis of the similarity of one of their features. The elementary time unit adopted is a five-day period of time, or a pentad, and the grouping characteristic is variable x, which is presented in the form of a discharge frequency distribution. The result of the testing procedure of the similarity of water discharge distributions is a quadratic similarity matrix of the yearly set of pentads in which the rows and columns are designated by the numbers of the pentads in chronological order. The matrix is pictured as a diagram presenting relations (links) holding among the pentads in terms of the similarity of their feature. A river regime is defined here as the type and temporal structure of river discharges in a normal hydrological cycle. The elements of the structure are so-called hydrological periods, which provide a tool for the study of a regime and a basis for its classification. Hydrological periods were determined twice: once on the basis of a 20-year set of discharges from years with extremely low values of Hurrell's NAO_{DJFM} index (NAO-), and then on the basis of a 20-year set from years with extremely high values (NAO+). Each hydrological period was described by means of six variables: the start and finish of the period, its duration (T), the coefficient of variation (Cv), the coefficient of skewness (S), and the coefficient of discharge (W) defining water abundance of the period. The types of hydrological period were established on the basis of the coefficient of discharge (W) according to the following criteria: $W < 0.5$ - a deep low; $0.5<W<0.75$ - an average low; $0.75<W<0.9$ - a shallow low; $0.9<W<1.1$ - a normal period; $1.1<W<1.25$ - a low flood; $1.25<W<1.50$ - an average flood; $1.50<W<1.75$ - a high flood; and $W<1.75$ - a very high flood.

Next, average characteristics of high- and low-flow seasons in a positive and a negative NAO stage were determined, compared, and the differences calculated. The research closed with a classification of the rivers in question carried out in terms of differences in the properties of the high- and low-flow seasons in the two NAO stages. In the classification procedure, use was made of Ward's method of hierarchical grouping. The variables describing hydrological periods were differences in the flow magnitude, duration, and starting date of a given period. The changing number, temporal structure, and parameters of the hydrological periods made it possible to assess the tendency of change in the hydrological regimes of European rivers in the different NAO stages, and to determine areas with the most variable and most stable parameters of the hydrological periods.

The analysis embraced 150 rivers flowing in a variety of environmental conditions obtaining in Europe. This area is highly interesting due to its diversified climatic conditions and a variety of conditions of river flow, which have produced five types of hydrological regime and whose variable atmospheric circulation has a well-documented effect on elements of the climate. In the study use was made of the daily discharge figures of at least 40-year observation series from the years 1901-2000. They come from the following sources: the Global Runoff Data Center, HYDRO banque nationale de données pour l'hydrométrie et l'hydrologie (France), Hydrometeorological Center of Belarus, Institute of Meteorology and Water Management (Poland), and Sistema Nacional de Informação de Recursos Hidricos (Portugal). The rivers selected for the research have small catchment areas. Those under 5,000 km^2 constitute 68%, and those under 1,000 km^2 - 27% of their total number. The remaining 32% are rivers with catchments exceeding 5,000 km^2. The largest, in excess of 100,000 km^2, account for a mere 4% of the rivers. They all have daily discharge observation series of at least 40 years. Rivers whose observation series cover from 60 to 70 years constitute the largest proportion (22%). The shortest series (from 40 to 50 years) and the longest ones (from 90 to 100 years) contribute 17% each. In the study use was made of NAO values calculated according to J. Hurrell's (1995) method and obtained by electronic means from http://www.cru.uea.ac.uk/cru/data/nao.htm.

RESULTS

On the basis of the grouping of rivers by change in the parameters of their high-flow periods, four basic groups can be distinguished, from A to D, with a total of 10 subgroups. Their spatial location is presented in Fig. 1. Owing to the small number of rivers analysed in the eastern part of the East European Plain, the presented division into groups in this part of the continent is only approximate (symbolised by a question mark).

Group A embraces rivers situated in the north of the continent - those of Norway, Sweden, central and northern Finland, northern Russia, Iceland, Ireland, western England and Scotland, and also central Germany and Denmark. They are characterised by a flow of greater volume, even up to 40%, during high-water seasons in a positive NAO stage. Subgroup A_1 includes rivers with floods in a positive NAO stage higher by an average of 10% to a maximum of 30%. On average, high-flow periods start then almost 3 weeks earlier and last markedly longer, statistically a month. This group is represented by rivers on the coast of Norway, in central Finland and in Scotland. Subgroup A_2 contains rivers with the biggest difference in the high-water flow between the two NAO stages. In a positive stage it is statistically 22% higher, but in some cases it can be even 40% higher. There are no marked differences in the starting dates and duration of the flood period. Rivers of this subgroup are primarily those of central Norway, northern Russia and Iceland. Subgroup A_3 comprises rivers with about 10% higher floods in a positive NAO stage. In both stages the staring dates of high-flow seasons are similar, but they last distinctly shorter, from an average of 2-3 weeks to a maximum of more than two months, in a positive NAO stage. Rivers of this group can be found primarily in western England, Ireland, and from the Alpine Foreland through Germany to Denmark.

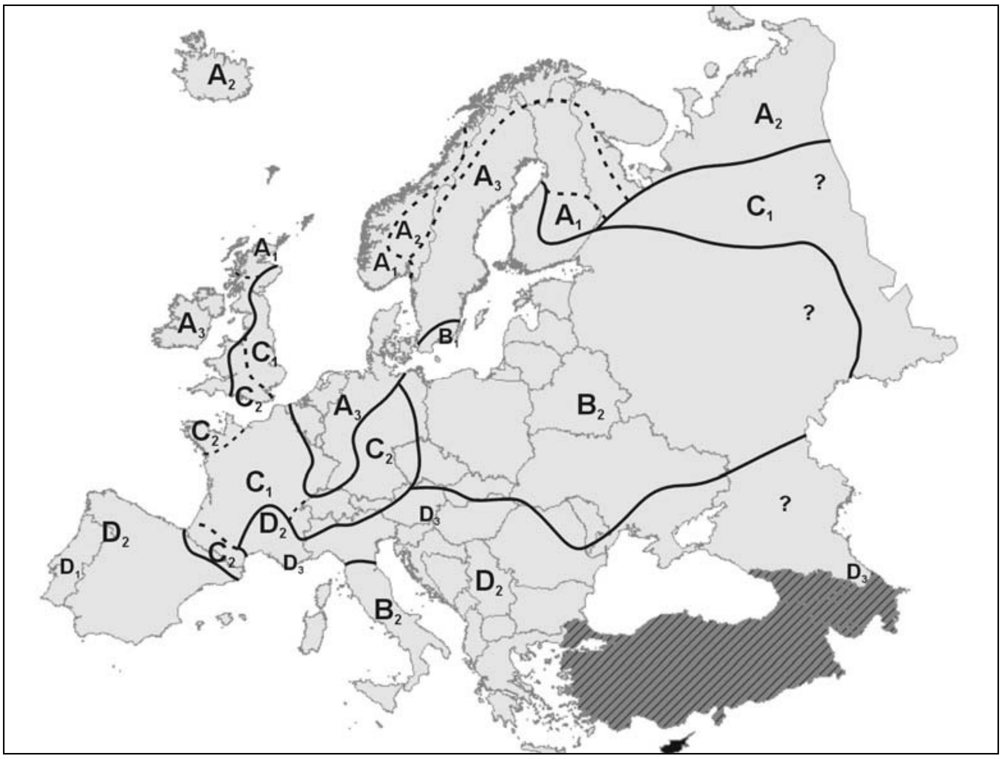

Figure 1. Typological classes of rivers by change in the parameters of flood periods in the different NAO stages.

Placed in group B are rivers of Central and Eastern Europe up to the Oka, as well as those of Corsica and the Apennine Peninsula. Rivers of subgroup B_1 do not occupy a compact area; they are dispersed throughout southern Sweden and central Norway. In a negative NAO stage their flood seasons display higher flows (about 10%), start statistically 1 month later and last shorter, sometimes even by 2-3 months. Subgroup B_2 is represented by rivers of Central Europe, western and southern Finland, Eastern Europe up to the Oka, Corsica, and the Apennine Peninsula. They differ from rivers of subgroup B1 in having a distinctly higher flow in a negative NAO stage, 30% on average, while high-flow seasons start then more than 3 weeks later and are about 1 month shorter.

Group C comprises rivers displaying the smallest differences in the analysed parameters of high-flow seasons between a negative and a positive NAO stage. They can be found in eastern England as far as Scotland, western France, the Pyrenees, the Alps, central Germany and the East European Plain, from the White Sea coast to the Urals. High-flow periods of subgroup C_1 rivers are characterised by about 10% higher floods in a negative NAO stage. There are no major differences between the two stages in the staring dates and duration of those periods. In subgroup C_2 flood flows and their staring dates are similar in the two NAO stages, but their duration is markedly longer, up to an average of 1 month, in a negative NAO stage. The group is represented mainly by Alpine and Pyrenean rivers, and those of southern England and central Germany.

Group D includes rivers of the Iberian Peninsula, southern France and the Massif Central, as well as the area extending from the Eastern Alps to the Balkans. Subgroup D_1 comprises rivers of central and southern Portugal. They stand out for their much higher (40 to 60%) floods in a negative NAO stage, and while the starting dates of high-flow seasons stay the same, their duration in that stage is markedly extended, by 45 days on average. Rivers of subgroup D_2 are characterised by about 15% higher flood flows in a negative NAO stage. The average starting date of high-flow seasons does not change much, but they are statistically more than 3 months longer than in a positive stage. This group embraces rivers of northern Portugal, most of those in the Massif Central, rivers of the Eastern Alps, the Balkans, and some of the central Danube basin. Rivers of subgroup D_3 are characterised by the same flow in both NAO stages and a decidedly earlier start, by more than a month, of the high-flow season in a negative stage and its much longer duration then, by more than 2 months. The rivers can be found in the south of France, the west Danube basin, and the Caucasus.

On the basis of the grouping of rivers by change in the parameters of their low-flow periods, also four groups were distinguished, from A to D, with 9 subgroups. However, since the rivers assigned to the various groups are often scattered throughout the continent, it was pointless to present the distribution of the typological classes graphically.

Group A embraces rivers whose low-water flows are decidedly higher in a positive NAO stage. The lows then usually start later (subgroups A_2 and A_3), and their duration does not change (subgroup A_1) or is markedly shorter (subgroups A_2 and A_3). This type is represented by some Portuguese rivers, those of western Norway, northern France, as well as Finland, Sweden, Lithuania and Estonia.

In group B a distinction was made between subgroups B_1 and B_2. Subgroup B_1 contains rivers with a slight, ca. 10%, domination of low-water flow and an earlier low-flow starting date in a positive NAO stage. In both NAO stages the duration of low-flow seasons is basically the same. The rivers of this group are found in Central Europe, from the Warta to the Dnieper, some are in the Alps and Pyrenees, and on the Jutland Peninsula. Flows in low-water seasons in subgroup B_2 are distinctly higher, more than 20%, in a positive NAO stage, and the seasons are 1 month longer then. Most rivers showing this type of change are situated in central and southern Norway.

Group C comprises rivers with higher flows in low-water seasons in a negative NAO stage, in subgroup C_1 even over 20%. No major differences in the starting dates and duration of lows can be observed between the two NAO stages. It is only rivers of subgroup C_1 which are characterised by longer, up to 2 months, lows in a negative NAO stage. They are situated in the British Isles, Germany, the Alps, and central Norway. There is a distinct clustering of subgroup C_2 rivers in northern Norway, Russia and Iceland.

Rivers of group D (subgroups D_1 and D_2) display low-water flows statistically 10% higher in a negative NAO stage, while the starting dates of lows are then decidedly delayed, by more than 1 month. The duration of those periods is markedly shorter, by more than 2 months in subgroup D_1 and more than 1 month in subgroup D_2. Rivers of this group are largely located in Central Europe (Germany, Czech Republic, Hungary), and also southern England, the Eastern Alps, and the south of Europe.

CONCLUSIONS

In terms of changes in the magnitude of flow, both in the low- and high-water periods, the rivers most susceptible to variations in the atmospheric circulation conditions include:

- those in Northern Europe (the Scandinavian Peninsula) which, in a positive NAO stage, show an increase in the flow, both at low and high water, a usually earlier start of flood periods and their longer duration, and a usually later start and shorter duration of lows;
- those in Central and Eastern Europe, characterised by a decided increase in the flood flow and a slight decrease in the low-water flow in a negative NAO stage. The starting dates of flood periods are then markedly delayed and their duration shortened. These regularities tend to diminish eastwards, however, and the observed differences in the parameters of high-water seasons in the two NAO stages become narrower;
- those in Southern Europe whose flow in flood seasons is decidedly higher and their duration markedly longer in a negative NAO stage.

The remaining area can be considered stable in terms of changes in high- and low-water flows in the two NAO stages. Its eastern boundary runs roughly longitudinally across eastern Germany south to northern Italy embracing the Alpine region, then farther west to the Mediterranean coast. It bypasses southern France and the Massif Central. The western boundary of this region is the Pyrenees. The presented method of analysis of the hydrological regime is also possible to employ in a research on the stability of regime parameters in the changing climatic conditions brought about by both, natural factors and human activity.

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Autonomous Adaptation to the Extreme Flood Events in Bangladesh as a Case: Can Adaptation in South Asia Cope with the Extreme Hydrological Profile of the GBM River Basins in Foreseeable Climate Change?

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ABSTRACT

IPCC, United States Country Study Program (USCSP) and UNEP have formulated vulnerability and adaptation to climate change guidelines where ‘autonomous adaptation’ is being emphasized. Adaptation as a factor of development in the foreseeable future under climate change conditions is crucial in this region. From 1988 to 1998 Bangladesh as well as the GBM River basins experienced several extreme floods which might have strong links with the current climate change. Literature on climate change associated with flood management over the GBM river basin as well as South Asia supports this argument.

It is found that crop adaptations of farmers in Islampur (case study area, located on the Brahmaputra/Jamuna in north-central Bangladesh) are very resilient in response to the hydrological profiles of extreme floods (peak discharge, depth, duration and multiple hydrological peaks at the same year) in 1988, 1995 and 1998. It is also found that farmers’ crop adaptation processes in respect to the great flood hydrological profile in 1998 have not been well adjusted, and these have exceeded farmers’ normal ‘crop-flood’ coping behavior; as a consequence the failure effects of autonomous adaptation are large – the results are currently being assessed. Literature associated with community adaptation in South Asia along with the result of case study analysis indicates that adaptation in response to the extreme floods’ hydrological profiles under the climate change conditions in future in South Asia would need to be urgently emphasized as the ‘crop-flood’ adaptation capacity of farmers in the region is going to be severely threatened, as evidenced in 1998.

The study has followed multi-method technique which is accompanied by Participatory Rapid Appraisal (PRA), questionnaire survey analysis, an unpublished household flood damage report *Chinaduli Union in Islampur,* literature review and professional judgments.

INTRODUCTION AND STATEMENT OF THE PROBLEM

Autonomous crop adaptation is a process which is commonly practised in Bangladesh as well as in the mega-delta: the Ganges-Brahmaputra-Meghna (GBM) River basins in South Asia farming system where annual riverine flooding is a common phenomenon. Farmers adapt with normal or extreme flood events where they use their own resources. Farmers make their decision whether they will plant the HYV *aman*[10] or rely on the local variety *aman* crop - this decision entirely depends on the nature of extreme flooding: number of flood peaks, duration, depth and frequencies.

Autonomous adaptation to climate change is a very important issue, as IPCC, UNEP and United States Country Study Program pointed out in their Vulnerability and Adaptation guidelines (Carter et al., 1994; Smith et al., 1996; UNEP & IES, 1996). IPCC WGAR4 is going to publish chapter 17 which is based on adaptation; Stern (2006) has also emphasized the adaptation to climate change issue. Therefore autono-

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[10] High Yielding Variety (HYV) *aman* is a major paddy, cultivated at the period of *kharif* 2 cropping season; it is a relatively longer maturation paddy than the local variety *aman.*

mous crop adaptations to extreme flood events have enormous implications for future development planning in Bangladesh as well as in South Asia, particularly in GBM River basins. Farmers follow different crop adaptation strategies according to their understanding of the different types of extreme floods and their hydrological peaks, duration, depth and frequencies. The question can be raised whether the extreme flood events in the GBM River basins are likely to be more frequent and worse or not? The paper summarises data on the past decade's autonomous crop adaptation processes in response to the extreme flood events. From these past experiences, a picture can be drawn of the severity and resilience of crop-flood adjustments of the extreme flood events. This leads to an analogue reference case for foreseeable future extreme flood events which might occur in this region. Is climate change likely to exaggerate extreme flood events in this region in future? The Fourth Assessment of Working Group 2 of the United Nations Intergovernmental Panel on Climate Change (UN IPCC) argued in the Asia section: "*Coastal areas, especially heavily-populated mega-delta regions in South, East and Southeast Asia, will be at greatest risk due to increased flooding from the sea, in some mega-deltas, flooding from the rivers*'' (Adger et al., 2007:8). The IPCC Third Assessment Report (2001) has also warned that extreme events have increased in temperate Asia, including floods, droughts and tropical cyclones. If indeed IPCC's predictions are so alarming in this region, it is obvious that the entire mega-delta of the GBM River basins would be at risk due to increased frequency of flood events. Other studies indicate that extreme flood events have dramatically increased in the past one and half decades in the GBM River basins (Younus, 2007a and 2007b, 2005a and 2005b; Prashad et al., 2004; Ahmad et al., 2004; Paudel and Sharma, 2004; Lal and Aggarwal, 2000; Lal, 1994).

If this is the case then farmers in this region would face more frequent extreme flood events in near future and as a consequence farmers' coping ability would be severely threatened. OECD declared '*That adaptation to climate change and its adverse effects is of high priority for all countries and those developing countries, especially the Least Developed Countries and Small Island Developing States are particularly vulnerable. The Least Developed Countries are among the most vulnerable to the adverse effects of climate change and in particular that widespread poverty limits their adaptive capacity*' (OECD Declaration, 2006:5). Bangladesh as a Least Developed Country would be more vulnerable to flooding and its poverty would reduce the adaptation capacity. If farmers lose their buying capacity due to frequent loss of their major crop *aman* then they cannot afford even their basic farming needs, seedlings and the cost of agriculture inputs. At this stage, food insecurity prevails, and farmers do not know how they will survive up to next cropping season, and how to manage household basic expenses. These multiple stresses act as an incremental force on the farming households. Each household has normally low annual income (A$ 58-175), and a high number of dependent family members, while in the majority of cases the head of the household is the only earning member, owning small and fragmented areas of land. As a consequence the country's capacity for crop-flood adaptation would obviously be threatened. IPCC also warned '*Many millions more people are projected to be flooded every year due to sea-level rise by the 2080s. Those densely-populated and low-lying areas where adaptive capacity is relatively low, and which already face other challenges such as tropical storms or local coastal subsidence, are especially at risk. The numbers affected will be largest in the mega-delta of Asia and Africa while small islands are especially vulnerable*' (Adger et al., 2007:7). Therefore Bangladesh as a densely-populated and low-lying area would face lower adaptive capacity with the extreme flood events as evidenced in the 1988, 1995 and 1998 flooding.

Objectives and Aim

Firstly the paper investigates the autonomous crop adaptation processes in response to extreme flood events; secondly it examines the failure effects of autonomous crop adaptation and other damages, and the consequences for the studied farmers.

METHODS

The study has followed multi-method technique which is accompanied by Participatory Rapid Appraisals (PRA), questionnaire survey analysis over 140 households in 2006 and 70 households in 1998, unpublished households (125) damage report of *Chinaduli Union in Islampur*, current literature review and professional judgments.

RESULTS

Table 1 describes the hydrological nature of normal and extreme flood events in the case study area. It also shows the autonomous adjustment processes in response to respective flood conditions which were executed by the farmers. The question arises: if the adjustment processes fail then what would be the crop related losses / damages in the studied households? The failure effects of autonomous crop adaptations (FEACAs) in the case study area including Bangladesh are large in an economic sense, and are defined as:

Table 1: Hydrological Nature of Flooding and their Respective Adjustments in Islampur

Flood Condition	Hydrological Nature of Normal/Extreme Flood Events	Autonomous Adjustments by Farmers
Normal Flood Condition	July 15 to August 15 is the normal flood period; single peak and short duration and reasonable depth of flood height is accepted for growing the seedlings.	Either *aman-boro IRRI-aus* or *aman-wheat-jute* planted*;* farmers in general attempt to plant HYV variety *aman* at *kharif* 2 which is well adjusted with normal flooding.
1988 Extreme Flood Year	Flood had single peak with high depth and volume, occurred quickly and receded quickly; the duration of flood water was shorter in comparison with the 1998 flooding; heavy local downpours occurred.	HYV *aman* was planted first but was entirely wiped out; the local variety of *aman* was then planted in the majority of cases, but some planted the HYV *aman*; this was *tactical adjustment.*
1995 Extreme Flood Year	Lower flood depths than in 1988 and 1998; flood depths exceeded the danger level for crops.	Replanted their *aman* seedlings a second time (majority chose HYV); this was *routine adjustment*.
1998 Extreme Flood Year	Farmers experienced three flood peaks with high depths of flood waters (a multi-peak flood).	Farmers attempted to plant seedlings at least three times, but every time were wiped out by a new peak; many planted seedlings for a fourth time in the hope of getting some return; this was *deliberate adjustment*.

$$\text{FEACAs} = \text{TECL} + N\,(\text{SC}+ \text{FC}+\text{PC}+ \text{LPC}+\text{LC}+\text{WC})$$

(TECL-Total Expected Crop Loss, N-Number of Floods Strike, SC-Seedling Cost, FC-Fertilizer Cost, PC-Pesticides Cost, LPC- Land Preparation Cost, LC- Labouring Cost, WC- Watering Cost).

Figure 1 indicates the household distribution scenarios of failure effects of autonomous crop adaptations in 1998, 1988 and 1995 in the Islampur case study. The total crop related loss due to failure effects of autonomous crop adaptations over 140 households in 1998 is *Tk* 6183167, in 1988 is *Tk* 7217559 and in 1995 is *Tk* 464954. In 1998 the total crop related loss due to extreme flooding in Islampur is *Tk* 1805288540 (A$35.26 Million); in 1988 is *Tk* 2107280428 (A$ 41.20 Million) and in 1995 is *Tk*

135749196 (A$ 2.7 Million). The failure effects of ACAs means, if autonomous crop adjustments fail in response to the extreme flooding then crop related loss due to extreme flooding in 1998 in Bangladesh is A$ $1.107149587\text{x}10^{10}$, in 1988 is A$$1.292355575\text{x}10^{10}$, and in 1995 is A$ 8325,24214.

In addition, total damage losses pertaining to plants and houses in 125 households in *Chinaduli* Union in Islampur in the 1998 flood year is also large as **Figure 2** indicates. The average damage loss for plants in each household is *Tk* 7171 and for houses is *Tk* 21665; and the total for plants and houses in each household is *Tk* 28836. The total number of households in Islampur is 40,876 (BBS, 1986). Therefore, in 1998 the total plants and house related loss due to extreme flooding in Islampur is *Tk* 1178700336 (A$ 22.66 Million); the total plants related loss in Islampur is *Tk* 293121796 (A$ 5.63 Million), and the total houses related loss in Islampur is *Tk* 885578540 (A$ 17.03 Million).

In summary the total average damages (crop related damage plus plants and houses damages) of each household in the studied area in 1998 extreme flood year is *Tk* 73001; and total damages in Islampur due to the extreme flood event in 1998 is A$ 57.92 Million. There were 314 *Thanas* which were affected by the 1998 flood; and Bangladesh occupies 60-70 per cent lands which are flood prone (Ahmad et al., 2005, 2000; Brammer, 1997). Therefore the crop related loss plus plants and houses damage due to extreme flooding in 1998 in Bangladesh is A$ 18186.88 Million.

Figure 1

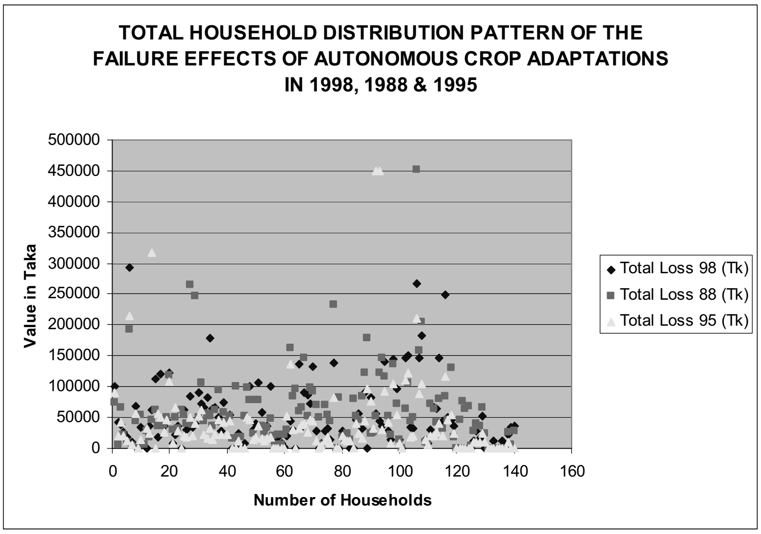
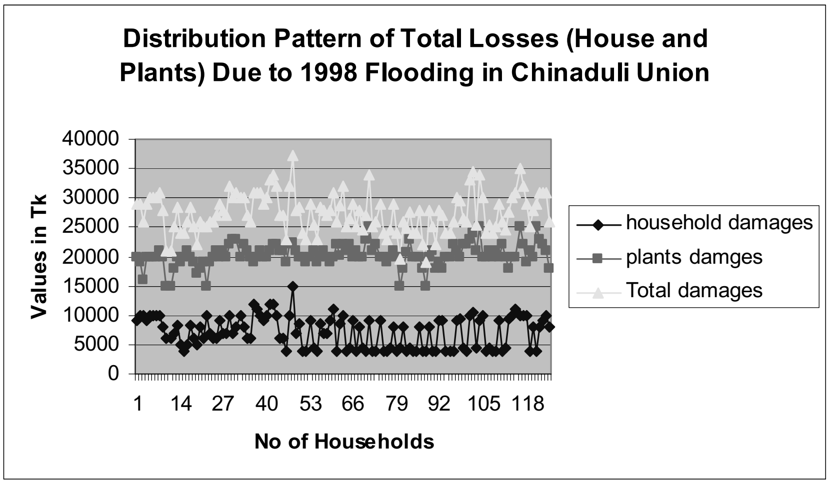


Figure 2



DISCUSSION AND CONCLUSIONS

The hydrological cycle of three extreme flood events and their outcome: the frequencies of flood peaks, duration and depths, and the respective crop-flood autonomous adjustments executed by farmers, have been observed in the period of 1988 to 1998. It was found that a) farmers' autonomous crop-flood adjustments are highly resilient in response to the extreme flood events; b) the multi-peaks floods, as in the 1998 flood, terminate the capacity of autonomous crop-flood adjustments i.e. during this period cultivation becomes impossible and the crop-flood adjustment processes fail; c) the failure effects of autonomous crop adjustments in response to three observed extreme floods are large in relation to the poor socio-economic and demographic settings of farming households in this region; d) further, the total damage loss relating to plants and houses is also large; e) extreme hydrological cycles, especially multi-peaks and longer duration floods, have increased during the last decade in this region. These observations have serious consequences in future if climate change accelerates the frequencies of multi-peaks and induces longer duration of extreme flood events in the GBM River basins in South Asia. Therefore it is urgently necessary to deal with this autonomous crop-flood adjustment issue in the future development planning process. In this regard, farmers' awareness of the likelihood of future extreme flood events, and capacity building to assist farmers to cope with extreme flood events need to be emphasized urgently in order to reduce the future vulnerability of extreme floods in South Asia, such as were experienced in 1988, 1995 and 1998. The concerned agencies, for example the local Water Board and Agriculture Offices, if adequately funded, can initiate the roles and actions which can improve farmers' crop-flood adaptation capacity in the future. A short maturing HYV crop which is resistant to the extreme flood events might be promoted by the agricultural agencies in order to enhance the capacity building of farmers to cope with the extreme flood events.

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Investigation on Variation of Drought Characteristics in Southern Taiwan

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Keywords: drought characteristic, standardized precipitation index, return period

ABSTRACT

Climate change is a worldwide issue. Recently, it seems that the drought problem is becoming more frequent in Taiwan. To investigate the characteristics of drought is the main purpose of this paper. Previous study (Yu *et al*., 2006) applied three statistical tests, Cumulative deviations, Mann-Whitney-Pettitt tests, and Kruskal-Wallis tests, to investigate the tendency of long-term annual precipitation. That study found that annual rainfall series in southern Taiwan have the same changing point in the 1950s and have a significantly decreasing tendency from ten observed gauges with at least 80-year historical data in southern Taiwan. The characteristics of drought, including drought duration and drought intensity, are further investigated based on Standardized Precipitation Index (SPI). First, analyses using the cumulative deviations tests yielded the change point of SPI3 (three-month SPI) series. The change points are around 1957, which is similar to those obtained by Yu *et al*. (2006). The SPI3 series is further divided into two periods according to the change point. Drought duration, severity, and intensity before and after change point are calculated based on two thresholds (SPI3＜0 and SPI3＜-1.0). Appropriate distribution is fitted for three drought characteristics in two SPI3 series before and after the change point. The return period of drought duration, severity, and intensity are compared to study the variation of drought characteristics in southern Taiwan. The analytical results provide the information of drought scale change in southern Taiwan.

INTRODUCTION

Numerous investigations have studied rainfall trends in various areas worldwide and have found that rainfall characteristics vary according to region, and have increasing or decreasing trends. Yu *et al.* (2006) found that annual rainfall in southern Taiwan has decreased significantly during the past century. The present work further investigates the variability of drought characteristics influenced by variability of precipitation using the Standardized Precipitation Index (SPI), in which precipitation is the only variable applied.

Karl *et al.* (1995) examined the proportion of land area in the United States experiencing either severe drought or severe moisture surplus. Makra *et al.* (2002), who used the Makra-test in Hungary, identified characteristic wet periods between 1901 and the 1940s, followed by a significant dry period lasting through the second half of the century (1940-1990s). A statistical method was employed by Al-Salihi (2003) in determining that droughts in Jordan have increased in frequency and duration. McKee *et al.* (1993) designed the SPI and applied it in the US. Guttman (1998), who compared the Palmer Drought Index (PDI) with the SPI, demonstrated that the spectral characteristics of the SPI do not vary among sites, whereas some in the PDI do. Guttman (1998) also showed that the PDI has a complex structure with an exceptionally long memory, whereas the SPI is an easily interpreted, simple moving average process. The SPI has the advantages of simplicity, variability of its time scale, and standardization. Because of the flexible time scale of the SPI, one can use a time scale appropriate for one region. Furthermore, the SPI can be easily compared between different regions due its standardization. Thus, the SPI is used herein.

Following the development of the SPI, many works have investigated drought variability based on the SPI. The analysis by Lloyd-Hughes and Saunders (2002) of European droughts in 1901-1999 indicated the mean number and duration of extreme droughts (SPI≤-2) on a 12-month time scale were 6±2 events and 27±8 months, respectively. Furthermore, Min *et al.* (2003), who applied SPI and spectral analysis to analyze monthly rainfall records for 1951-1996, showed that the drought frequency increased significantly in Korea after 1980. Spatial and temporal analysis of droughts on the Iberian Peninsula from 1910-2000 was performed by Vicente-Serrano (2006). They identified the main drought episodes using the SPI, with the most intense droughts recorded in the 1940s, 1950s, 1980s, and 1990s. Those studies provided pictures of changes to drought characteristics in various areas. The main objective of this work is to study the variability of drought characteristics in the southern Taiwan using existing records.

Taiwan is an island covering 36000 km^2, and is located in the western Pacific Ocean. Long-term rainfall records comprise a valuable historical database, which can be used for statistical analysis of drought variability using the SPI. Such an analysis based on a historical data can accurately reflect local statistical characteristics, providing useful information for global drought studies.

STUDY AREA

Southern Taiwan, chosen as the study area, is subjected to large variations in seasonal rainfall. Many raingauges are distributed throughout southern Taiwan. However, most raingauge records are not long enough for studying long-term drought variability. Only eight raingauges have data over 80 years. Figure 1 lists the location of these raingauges. Monthly rainfall records of four raingauges are missed for less than four years. Reconstruction of missing data was made up by single and multiple regression with resort to records in neighbour raingauges, because long-term records are very valuable. Significance of the regression formulae were confirmed by the F test. The monthly rainfall records with reconstructed data in eight raingauges were then used to calculate SPI3.

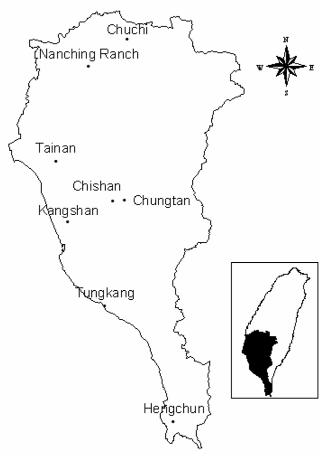

Figure 1. The spatial distribution of raingauges in southern Taiwan

METHODS

The SPI was developed by McKee *et al.* (1993) to quantify precipitation deficits using multiple time scales. Different time scales are suited to different types of drought events. Szalai and Szinell (2000), who assessed the utility of the SPI for describing drought in Hungary, concluded that the SPI is suitable for quantifying most types of drought events. Detailed procedures for calculating the SPI can be found in Lloyd-Hughes and Saunders (2002). McKee *et al.* (1993) defined an SPI less than 0, -1.0, -1.5, and -2.0 as mild drought, moderate drought, severe drought, and extreme drought, respectively.

A test of data homogeneity, the cumulative deviations test (Buishand, 1982) suggested by the World Meteorological Organization, is undertaken to verify the presence of trends in SPI3. The homogeneity test is based on adjusted partial sums or cumulative deviations from the mean. Significant level of 0.05 is used in the statistical tests.

Traditional frequency analysis based on annual maximum series cannot be applied to drought frequency analysis because drought events are usually across years. Therefore, an alternative method derived by Shiau and Shen (2001) is adopted in this study. The return period equation can be written as:

$$R_X = \frac{E(Int)}{1 - F(x)} \tag{1}$$

Where R_X is the return period for $X \geq x$; $E(Int)$ is the average of interarrival time of droughts; $F(x)$ is a cumulative distribution function, and x is a specific value of drought variable. Drought events are extracted using runs theory (Yevjevich, 1967) in advance. Two thresholds (SPI3<0 and SPI3<-1) are then employed in this study. Drought duration, severity, and intensity are fitted by appropriate probability distribution functions, i.e. Exponential and Gamma distribution functions. All distribution functions are examined by Kolmogorov-Smirnov test.

RESULTS

The results are presented in the following. First, the change point of SPI3 time series was determined by cumulative deviations test. On the basis of the change point, drought events before and after the change point were extracted according to two thresholds (SPI3＜0 and SPI3＜-1.0). Then, comparison of drought characteristics (drought duration, severity, and intensity) was determined. Finally, the return periods of three variables were estimated to evaluate the frequency variation between two periods.

SPI3 time series changes

Cumulative deviations test was used to detect the change point of SPI3 series. Table 1 lists the analytical results of change point test. The change points of eight raingauges are around 1957. The SPI3 series before and after the change points are statistically significant for all raingauges. The change points are similar to the annual rainfall trend found by Yu *et al.* (2006).

Table 1. Change points for the SPI3 time series determined by cumulative deviations test (Note: The number in **bold** indicates a statistically significant difference.)

Station Name	Observed Period	Change points	$Q/\sqrt{n}$
Chuchi	1904-2005	1954/04	**1.60**
Nanching Ranch	1916-2005	1957/07	**3.58**
Kangshan	1924-2005	1957/07	**2.24**
Chungtan	1916-2005	1954/04	**3.74**
Chishan	1911-2005	1957/08	**2.58**
Tungkang	1904-2005	1961/11	**2.91**
Tainan	1900-2005	1957/07	**2.58**
Hengchun	1900-2005	1961/11	**2.26**

Characteristics of drought events

Drought events were separated into two samples based on the change point. Average changes of each drought variables were determined. Drought severity defines as the sum of absolute SPI3 of a drought event. Drought severity divided by drought duration is defined as drought intensity. Table 2 presents the average change of drought characteristics before and after the change points. Drought duration for two thresholds is increased after change point. Drought severity shows the same pattern as drought duration. However, drought intensity does not demonstrate differences between two periods because both drought duration and severity increased simultaneously after change point.

Table 2. Average drought characteristics before and after change point with two thresholds (ADD: Average Drought Duration; ADS: Average Drought Severity; ADI: Average Drought Intensity)

Station Name	Data Period	SPI3<0			SPI3<-1		
		ADD	ADS	ADI	ADD	ADS	ADI
Chuchi	1904/01-1954/04	3.26	2.48	0.61	1.86	3.14	1.50
	1954/05-2005/12	3.63	2.88	0.65	1.75	2.65	1.45
Nanching Ranch	1916/01-1957/07	2.87	1.80	0.53	1.57	2.23	1.46
	1957/08-2005/12	3.62	2.85	0.61	1.91	2.96	1.46
Kangshan	1924/01-1957/07	2.90	1.82	0.59	1.33	1.85	1.31
	1957/08-2005/12	3.83	3.08	0.63	1.58	2.51	1.48
Chungtan	1924/01-1954/04	2.93	1.83	0.52	1.52	2.35	1.51
	1954/05-2005/12	3.98	3.07	0.63	1.78	2.72	1.48
Chishan	1911/01-1957/08	3.22	2.39	0.65	1.63	2.43	1.43
	1957/09-2005/12	3.48	2.95	0.64	2.02	3.09	1.46
Tungkang	1904/01-1961/11	2.65	1.77	0.57	1.46	2.22	1.44
	1961/12-2005/12	4.32	3.85	0.71	2.00	3.40	1.53
Tainan	1900/01-1957/07	3.07	2.21	0.65	1.58	2.39	1.42
	1957/08-2005/12	4.32	3.64	0.71	1.80	2.79	1.50
Hengchun	1900/01-1961/11	3.14	2.21	0.64	1.60	2.34	1.44
	1961/12-2005/12	4.11	3.52	0.63	2.20	3.47	1.47

Estimation of drought return periods

Three variables of drought characteristics were fitted to suitable probability distributions. Drought duration was fitted by Exponential distribution function. Twenty-nine samples were fitted as Exponential distribution function at significant level of 0.01, except 3 samples. Drought severity and intensity were fitted as Gamma distribution function. All samples of drought severity and intensity were fitted as Gamma distribution function at significant level of 0.01. The cumulative distribution functions were then used for drought frequency analysis.

Six return periods, which are two, five, ten, 20, 50, and 100 years, were used in this paper. Figure 2 plots the drought duration changes for six return periods. The drought duration determined by SPI3 less than -1.0 was shorter than those determined by SPI3 less than zero, due to the strict drought definition. Generally, drought duration prolongs after change point for the same return period pertaining to two thresholds. This means that the occurrence of a drought with a specific duration is becoming more frequent. For example, a drought with duration of 8.5 months has a return period of ten years in the former period, and that kind of drought in the latter period has a return period of approximate five years.

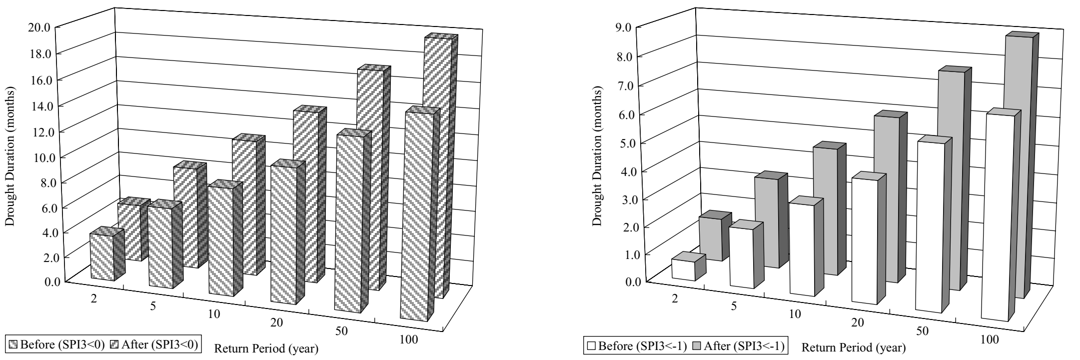

Figure 2. Drought duration frequency analysis before and after change point regarding two thresholds

Figure 3 displays drought severity frequency analysis for two periods pertaining to two thresholds. The value of drought severity determined by SPI3 less than zero is larger than that determined by SPI3 less than -1.0 because of the definition of drought threshold. Drought severity of a specific value pertaining to two thresholds happened more frequently in the latter period after the change point. The drought severity regarding SPI3 of threshold zero was dramatically severer than that regarding SPI3 of threshold -1.0 in the latter period. A 100-year return period relating to severity value is ten before the change point, while the same severity value corresponds to only about ten-year return period after change point. As for the drought intensity, the occurrence of a drought with a specific intensity value in the latter period is a little more than that in the latter period (details are not shown in this paper).

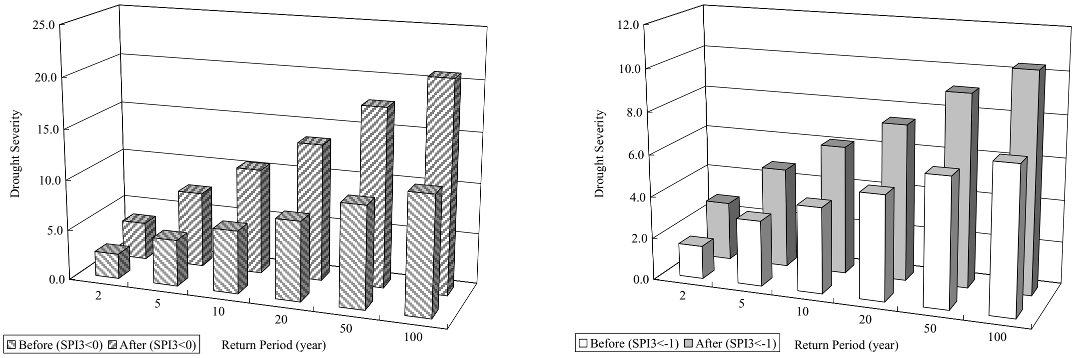

Figure 3. Drought severity frequency analysis before and after change point regarding two thresholds

DISCUSSION AND CONCLUSIONS

This paper uses SPI3 series to represent long-term meteorological drought in southern Taiwan. The SPI3 series was tested by cumulative deviations test, and it is found that the change points are around 1957. The SPI3 series was divided into two series according to the change point to study if these series have different drought characteristics. Drought events are defined by two thresholds of SPI3, and then their characteristics, i.e. duration, severity, and intensity, were investigated. The analytical results show that both drought duration and severity increase in the latter period.

Frequency analysis of three drought characteristics was employed regarding two SPI3 series before and after the change point. Drought duration is fitted as Exponential distribution function, and drought severity and intensity are fitted as Gamma distribution functions. Results of drought frequency analysis reveal that drought severity and duration become greater after the change point around 1957 in viewpoint of return period. This indicates that drought severity and duration with a specific value occur more frequently in the latter period after the change point. Conclusively, meteorological drought is becoming severer in southern Taiwan based on the statistic study of historical rainfall records.

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Behavior of Climate versus Food Security in Bangladesh

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Keywords: climate, vulnerability, food security, adaptation, preparedness

ABSTRACT

There is a wide interest in, and support for, for the idea of treating water as an economic good. Water is not just a commodity like oil or copper; it is the fundamental basis of life on earth. We have to realize that water is finite, and it needs to be used and shared more equitably not just among people and among countries but also between ourselves and nature.

Water is a renewable resource, availability is variable and limited. Nearly every country in the world experiences water shortage during certain times of the year. Factors such as rainfall, temperature, evaporation, and runoff determine clean water availability. Clean water resources per capita are declining rapidly as the needs of the growing population increase. Water resources depend on the hydrologic cycle, on the climate change, and to some degree on fossil water in the ground.

Bangladesh is likely to be one of the most vulnerable countries in the world to climate change. Both a situation of water abundance or water scarcity may become a natural threat for the people of Bangladesh. The climate is tropical; mild winter (October to March); hot, humid summer (March to June); humid, warm rainy monsoon (June to October). People follow a whole range of activities or strategies for their livelihood. Ensuring food and water is a key element in the livelihood strategies that people pursue. Water is essential for life and is used for drinking, cleaning, in the agricultural production system, and navigation. Adaptation requires assessment of vulnerability from the view point of different disciplines, which then requires an integrated approach to address.

Water contributes to achieving food security by influencing the food production process. In a flood situation, when there is excess supply of water and the height of the water table exceeds certain limit, it disrupts the food production and distribution system reduces people's purchasing power. Again, low water flow can lead to a drought situation when normal agricultural production practices get interrupted. Thus, both a situation of water abundance or water scarcity may become a threat to food security (Anjan Dutta). Moreover, the attainment of food security through water resources development has an external context. Bangladesh being a lower riparian country is not in a position to design an effective water management strategy without the cooperation of its neighbours. This is due to fact that of 230 rivers which cut across Bangladesh, 57 are Transboundary Rivers (54 coming from India and 3 from Myanmar). These rivers drain a total catchments area of 1.72 million square kilometers, of which only 7 per cent lies within the country, and 93 per cent is beyond its territory. The regional and transboundary issues thus have serious implications for the water resources planning and consequent food security in Bangladesh

INTRODUCTION

Bangladesh is a disaster-prone country. Almost every year, the country experiences disasters of one kind or another- such as tropical cyclones, storm surges, coastal erosion, floods, salinity and droughts- causing heavy loss of life and property and jeopardizing the development activities. The global warming due to the increase in the greenhouse gas concentrations in the earth's atmosphere and the consequent sea level rise (SLR) are going to add fuel to the fire. Almost every sector of life in Bangladesh is likely to be affected by climate change (Anwar Ali 1999).

COASTAL GEOMORPHOLOGY

The geographical location and geomorphological conditions of Bangladesh have made the country one of the most vulnerable ones to climate change, particularly to SLR. Bangladesh is situated at the interface of 2 different environments, with the Bay of Bengal to the south and the Himalayas to the north. This peculiar geography of Bangladesh causes not only life-giving monsoons but also catastrophic ravages of natural disasters, to which now are added climate change and SLR.

The country has a very low and flat topography, except the northeast and southeast regions. About 10% of the country is hardly 1m above the mean sea level (MSL), and one-third is under tidal excursions. The country has 3 distinct coastal regions-namely, western, central, and eastern coastal zones.

TROPICAL CYCLONES

About 80 tropical storms (tropical cyclones with wind speeds greater than or equal to 17 m s-1) form in the world's waters every year (McBride 1995). Of these, about 6.5% form in the North Indian Ocean(Bay of Bengal and Arabian Sea) (Neumann 1993). Since the frequency of cyclones in the Bay of Bengal is about 5 to 6 times the frequency in the Arabian Sea (IMD 1979), the Bay of Bengal share comes out to be about 5.5%. The breakdown of this 5.5% for the littoral countries of the Bay of Bengal is given in the last row of Table 1. Bangladesh is hit by about 0.93% of the world's total tropical storms, India by 3.34%, Myanmar by 0.51%, Sri Lanka by 0.22%, and 0.50% die in the Bay without hitting any country. These numbers were arrived at by considering the tropical storms that formed in the Bay of Bengal during the period 1877 to 1995.

Table 1. Number of cyclones forming in the Bay of Bengal and hitting the littoral countries (1877 to 1995). CS: cyclone storm; SCS: severe cyclone storm

Type	Bangladesh	India	Myanmar	Sri Lanka	Dead	Total
All types	154	848	71	35	115	1223
Depressions	68	539	24	15	69	715
CS	43	197	23	12	35	310
SCS	43	112	24	8	11	198
CS+SCS	86	309	47	20	46	508
Percent of global total						
CS+SCS	**0.93**	**3.34**	**0.51**	**0.22**	**0.50**	**5.5**

STORM SURGES

Storm surges are generated by the winds and the atmospheric pressure changes associated with cyclones. Wind is the main contributing factor. It exerts stress on the water underneath, and surge is generated. In Bangladesh, storm surge heights in excess of 10 m are not uncommon. A few examples of storm surge heights are given in Table 2 in the column under 'business as usual'-meaning normal conditions (that is, no climate change). Only those cyclones are included in which there was a death toll of at least 1000. Shallow water in the north Bay, the northward-converging nature of the Bay (at the head of which Bangladesh is situated), and high astronomical tides are the main causes of storm surge amplifications on the Bangladesh coast. The country's low and flat terrain is easily flooded by amplified surge waters, thus converting the coastal land area into a vast sea.

Table 2. Storm surge scenarios for cyclones affecting Bangladesh since 1960, each of which caused at least 1000 human deaths. Business as usual: no climate change; 2 and 4 C: lower and upper bounds of the rise in temperature by 2010, as given by the IPCC.

	Storm surge height (m)

Cyclone date	Deaths	Business as usual	2*C	4*C
Oct 9, 1960	3 000	3.05	3.69	4.55
Oct 30, 1960	5 149	4.57 – 6.10	5.53 -7.38	6.80– 11.00
May 9, 1961	11 468	2.44 – 3.05	2.95 – 3.69	3.64 – 4.55
May 28, 1963	11 520	4.27 – 5.18	5.17 – 6.27	6.36 – 7.72
May 11, 1965	19 279	3.66	4.43	5.45
May 31, 1965	12 000	6.10 – 7.62	5.53 – 9.22	11.00 – 11 .35
Nov 12, 1970	500 000	6.10 - 9.14	5.53 – 11.06	11.00 – 13.62
May 25, 1985	11 069	3.05 – 4.57	3.69 – 5.53	4.55 – 6.80
Nov 29, 1988	5 708	1.52 – 3.05	1.84 – 3.69	2.27 – 4.55
Apr 29, 1991	138 000	6.10 – 7.62	5.53 – 9.22	11.00 – 11.35

COASTAL EROSION

Erosion in the coastal area of Bangladesh is another big point of concern for Bangladesh. Heavy discharge currents through the Ganges-Bramaputra-Meghna river system, wave action due to strong southwest monsoon winds, high astronomical tides, storm surges in the Bay of Bengal are the main causes of erosion (and accretion) in the coastal area of Bangladesh. Superimposed on these causes, SLR has a long-term effect on coastal erosion in the country.

The loss of land area under 0.3 and 0.75 m SLRs was calculated. The result comes out to be 5.80 and 11.20 km.sq, respectively. About 95% of the area is agricultural land. In this sense, loss in food grain production with respect to the present will be about 13 750 and 252 000 metric tones, respectively.

BACK WATER EFFECT

Back Water Effect (BWE) generally refers to the retardation of a river outflow by a rise in the level of water at the mouth of the river. The effect may be from a main river to tributary or from sea to a river. Mostly it is an estuarial phenomenon. Not only do conditions at the mouth of the river retard the outflow, but often a flow reversal occurs- that is, water may flow from the sea to a river. BWE is very pronounced in Bangladesh, particularly in the Meghna river estuary, through which about 90% of the river water in the country discharges into the Bay of Bengal. It is particularly important during flood seasons. As a consequence, floodwater inside the country continues to accumulate, bringing more areas under inundation and increasing the length and depth of inundation in areas already inundated, thus further aggravating the flood situation that already exists.

FLOOD

The seasonal flooding can turn into a disaster with unusual rise of water , which is a frequent phenomenon in Bangladesh. During the last decade, floods occurred almost every year, the latest being the flood of 1998 when half of the country went under water for a couple of months. The extent of damage due to floods is substantial. The loss is not limited to standing crops only but also extends to the lives of cattle and poultry. This often leads to complete destitution of households.

All rice crops, in some way or other, are affected by floods. In the pre-monsoon period (mid-April to mid May) , flash floods often damage boro rice. Floods affect aus and aman during the monsoon and immediate post-monsoon periods. This happens because of the geographical location of Bangladesh and elevation of its land. Based on elevation, the land is classified into five categories as presented in Table 3 (Anjan Dutta 2001).

Table 3. Distribution of land according to elevation and extent of flooding

Land type	Description	Depth of inundation (in cm)	Duration (month)	Area (million ha.)	Area (%)
F0	High land	Not flooded	-	3.514	37
F1	Medium	30-90	1-3	3.288	34
F2	Low medium	90-180	2-4	1.558	16
F3	Low	180-300	3-5	1.124	12
F4	Very low	over 300	4-6	0.078	1

Bangladesh being a lower riparian country is not in a position to design an effective water management strategy without the cooperation of its neighbors. This is due to fact that of 230 rivers which cut across Bangladesh, 57 are transboundary rivers(54 coming from India and 3 from Myanmar). These rivers drain a total catchments area of 1.72 million square kilometers, of which only 7 per cent lies within the country, and 93 per cent is beyond its territory. The regional and transboundary issues thus have serious implications for the water resources planning and consequent food security in Bangladesh

DROUGHT

Drought is reduction in water availability. It refers to a situation when water availability restricts switching over to more water demanding crops. Therefore, drought is an indication of the vulnerability of present or planned cropping practices when water availability is below expectation. Such vulnerability could be measured by differences in agricultural production under expected and dry climatological and hydrological conditions. The degree of draught intensity and percentage loss of yield for some selected crops as presented in Table 4, demonstrate that a significant amount of food is damaged due to drought.

Table 4. Yield reduction of crops during rabi, pre-kharif and Kharif seasons due to drought

Degree of intensity	Yield reduction of crop During Kharif	Reduction of yield (in %) during Rabi and Pre-Kharif		
	Aman paddy	Wheat	Potato	Mustard
Very severe	Over 45	60-70	over 70	over 50
Severe	35-45	50-60	60-70	40-50
Moderate	20-35	40-50	50-60	30-40
Less moderate	n.a	30-40	40-50	20-30
Slight	less 20	less 30	30-40	less 20

SALINITY

The salt intrusion length generally varies with the hydrological condition. It is highest in the dry season and lowest in the wet season. Salinity directly affects the food production system. The present agricultural practices can tolerate salinity up to a limit of 1ppt (parts per thousand). However, due to flow of water in the dry season, resulting from withdrawal of water in the upper reaches of the Ganges, the zone of salinisation with 1 ppt in the Ganges-dependent areas of southwest Bangladesh are gradually expanding. According to an estimate , during 1967, the salinity of 1 ppt covered about 58 per cent of the southwest region while in 1995 this had gone up to 75 per cent (EGIS 1999). This implies that during this period about 2,750 sq.km of additional area has been affected by increased salinisation. The adverse impact of salinity is not limited only to field crops; it also affects homestead vegetation, water quality and many other economic activities, which people used to engage in a fresh water ecosystem.

ADAPTATION

Although Bangladesh is an insignificant or virtually zero contributor to the greenhouse gas emissions that affect global climate change, it is ironic that it has to suffer so disastrously from the effects of climate change that are likely to occur in the coming decades. It must, therefore, adapt itself to the changing circumstances. Adaptation requires assessment of vulnerability from the viewpoint of different disciplines, which then requires an integrated approach.

We have three adaptive options: retreat, accommodation and protection. Considering the high population density, future population projections, and shortage of land, retreat is not feasible. Rather we should pursue the two other options. One of the most immediate and useful adaptation strategies should be to protect the mangrove forest from denudation and implement a massive afforestation program all along the coastal belt. In fact, Bangladesh has a couple of ongoing projects aiming at that.

Afforestation will also help stabilize the land, create more accretion leading to more land, and also raise the level of topography that will reduce inundation by SLR.

Cropping practices may also be changed in the coastal area. New rice varieties may be developed to withstand higher salinity and higher temperatures and be grown and harvested during the non-cyclonic period.

Bangladesh has undertaken a massive program of constructing cyclone shelters in the coastal area. These specially built shelters will be used as shelters for human beings, animals, and property during cyclonic periods and as community centers, schools, and so forth during normal times.

Construction of embankments in the coastal area is another adaptation and protection measure. Embankments will obstruct the penetration of surge water; and even if the surge overtops them, the water energy will then be greatly reduced.

CONCLUSION

Water is not just a commodity like oil or copper; it is the fundamental basis of life on earth. We have to realize that water is finite, and it needs to be used and shared more equitably not just among people and among countries but also between ourselves and nature.

Water is a renewable resource, availability is variable and limited. Nearly every country in the world experiences water shortage during certain times of the year. Factors such as rainfall, temperature, evaporation, and runoff determine clean water availability. Clean water resources per capita are declining rapidly as the needs of the growing population increase. Water resources depend on the hydrologic cycle, on the climate change, and to some degree on fossil water in the ground.

People follow a whole range of activities or strategies for their livelihood. Ensuring food and water is a key element in the livelihood strategies that people pursue. Water is essential for life and is used for drinking, cleaning, in the agricultural production system, and navigation. Adaptation requires assessment of vulnerability from the view point of different disciplines, which then requires an integrated approach to address.

One of the best ways to adapt to climate change is to involve people at the grass-root level. The people of Bangladesh are very enterprising and innovative. They have been living with disasters for a long. Adapting to changing situations is a familiar traditional practice. What is important is to carry out detailed scientific studies to make the people aware of the impending dangers, and to develop, along with them, methods of adaptation.

Water contributes to achieving food security by influencing the food production process. In a flood situation, when there is excess supply of water and the height of the water table exceeds certain limit, it disrupts the food production and distribution system reduces people's purchasing power. Again, low water flow can lead to a drought situation when normal agricultural production practices get interrupted. Thus, both a situation of water abundance or water scarcity may become a threat to food security. Finally, it is nature, not the man is in charge of situation of Bangladesh.

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THE APPLICATION OF THE CONCEPTUAL MODEL METQ FOR SIMULATION OF DAILY RUNOFF AND WATER LEVEL FOR THE WATERSHED OF LAKE BURTNIEKS

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Keywords: Hydrological models, mathematical modelling of hydrological processes, reservoir routing, the Lake Burtnieks

ABSTRACT

The conceptual model METQ has been applied more than 10 years in modeling the hydrological regime (runoff and water level) of rivers or lakes in Latvia. The model has successfully proved for both small (the Vienziemite Brook, 5.92 km^2) and large (the Daugava River, 81 000 km ^{2}) drainage basins. The model MEQ has many modifications and in this research we are going to present the last one version METQ2007BDOPT.
This study has been carried out by modeling the hydrological regime with reference at the gauging station Salaca-Mazsalaca (A=2250km^2). The flow of the Salaca River is regulated by the Burtnieks Lake with a surface area of 40.06 km^2 and a drainage area of 2180 km^2. In present study the Lake Burtnieks watershed (part of the Salaca River basin) is divided in 4 sub-basins and one additional sub-basin between an outlet of the Lake Burtnieks and a gauging station Mazsalaca at the River Salaca. The obtained results show good coincidence between the measured and simulated daily discharges. To analyses the results a statistical criterion R^2 (Nash and Sutcliffe 1970) and a correlation coefficient r are used. The efficiency criterion R^2 is 0.9 and correlation coefficient r – 0.95.

INTRODUCTION

The Lake Burtnieks is the fourth largest lake in Latvia and locates in North-Easter part of Latvia. The lake is the source of the River Salaca, in which valley one of the largest complex of nature reserves in Latvia is located. The surface area of lake is 40.06 km^2, and total drainage area - 2215 km^2 (which occupies 62% of the River Salaca Basin). The Lake Burtnieks is shallow with average depth - 2.2 m. The climate is temperate, cool and humid. The average temperature of a year ranges from +5.0 to +5.5 ^{o}C. The mean temperature is -6.5 ^{o}C in January and +17 ^{o}C in July. The average amount of precipitation ranges from 650 to 760 mm per year.
During last centuries different management actions have been carried out in the Lake Burtnieks watershed. One of the explanations is that not all parameters of hydrological regime have been observed. Therefore, mathematical model as one of more accepted tools in hydrology could be use.

METHODS

The mathematical model of the Lake Burtnieks watershed is based on the specific hydraulic routing model of the Lake Burtnieks and the conceptual models METUL and METQ98 (Krams and Ziverts 1993; Ziverts and Jauja 1999) which are successfully applied to a relatively large river basin in Latvia as the River Daugava. The model METQ2007BDOPT is a mathematical model applied for the simulation of the daily runoff and evaporation for the rivers with different catchment areas. Input data for the model are daily meteorological data. The model can be classified as conceptual model and has 23 parameters. However, most of the parameters are physically based and the rest of parameters could be estimated by the calibration.

In present study for the simulation of the daily runoff of the Lake Burtnieks watershed are used the observed mean daily air temperature, precipitation and vapour pressure deficit data at fife stations from 1990 to 1999 have been used (Table 1). The time series at least 5-year period of four river discharge and one water level of the lake (Burtnieki) stations for a calibration of developed watershed model have applied (Table 2).

Table 1. Meteorological daily data used as input data in model

Station	Precipitation	Temperature	Vapour pressure deficit
Rujiena	01.01.90 - 01.12.99	01.01.90 - 01.12.99	01.01.90 - 01.12.99
Burtnieki	01.01.90 - 01.12.99		
Oleri	01.01.90 - 01.12.99		
Mazsalaca	01.01.90 - 01.12.99		
Valmiera	01.01.90 - 01.12.99		

Table 2. River discharge and water level of the lake stations with daily data used in calibration

Station	Discharge data	Water level data
Dravnieki	01.01.90 - 31.12.97	
Oleri	01.01.94 - 31.12.99	
Vilnisi	01.01.94 - 31.12.99	
Mazsalaca	01.01.94 - 31.12.98	
Burtnieki		01.01.93 - 31.12.99

To consider the runoff heterogeneity in runoff processes the studied catchment area of lake Burtnieks are divided in hydrological response units (HRU) characterised by a relative homogeneity with respect to the most important parameters, which includes slope, vegetation and soil characteristics. Catchment area is divided in 6 HRUs: agricultural lowlands, hilly agricultural lands, forests, swamps, sands and lakes.

The water balance and runoff of each HRU has been simulated in three storages: snow (water content in snow cover), soil moisture (water in the root zone) and groundwater (Fig. 1).

The total runoff from each of HRU consists of three runoff components: Q_1 - surface runoff, Q_2 - subsurface runoff (runoff from the groundwater upper zone) and Q_3 - base flow (runoff from the groundwater lower zone). The snow accumulation and melting routine in the model is similar to the one used in the HBV model (Bergström 1992). The main difference between the METQ and HBV models is that the degree-day ration in METQ does not have a constant value, but it has a temporal difference depending on the daily potential isolation of each particular day (Ziverts and Jauja 1999).

Snow accumulation and melting characterises the following parameters: T1 –daily mean temperature ^{0}C, at which starts snow accumulation; T2-daily mean temperature at which starts snow melting; CMELT is degree – day ratio and characterise intensity of snow melting; AMELT - conversation factor which increase degree- day ratio on the daily potential isolation of each particular day; KS – evaporation coefficient from snow; WHC and CFR characterise the snow accumulation and melting processes.

The water balance from root zone characterise: WMAX – threshold value of water storage in root zone (mm); KU and KL – coefficients characterise the intensity of evaporation from the root zone; RCHR, RCHRZ, RCHR2, RCHR2Z un ROBK – characterise the infiltration capacity of soil.

The water balance of groundwater storage and runoff characterise following parameters: ALFA – fillabale porosity of the aquifer; ZCAP – height of capillary rise (cm); DZ –depth of upper level drain from; A2 and Beta characterize daily subsurface runoff Q2 of upper level „drain"; PZ characterises the depth of the lower level "drain"; A3 - the daily runoff Q3 of the lower level "drain"; DPERC is intensity of the deep percolation to the aquifers, mm/day.

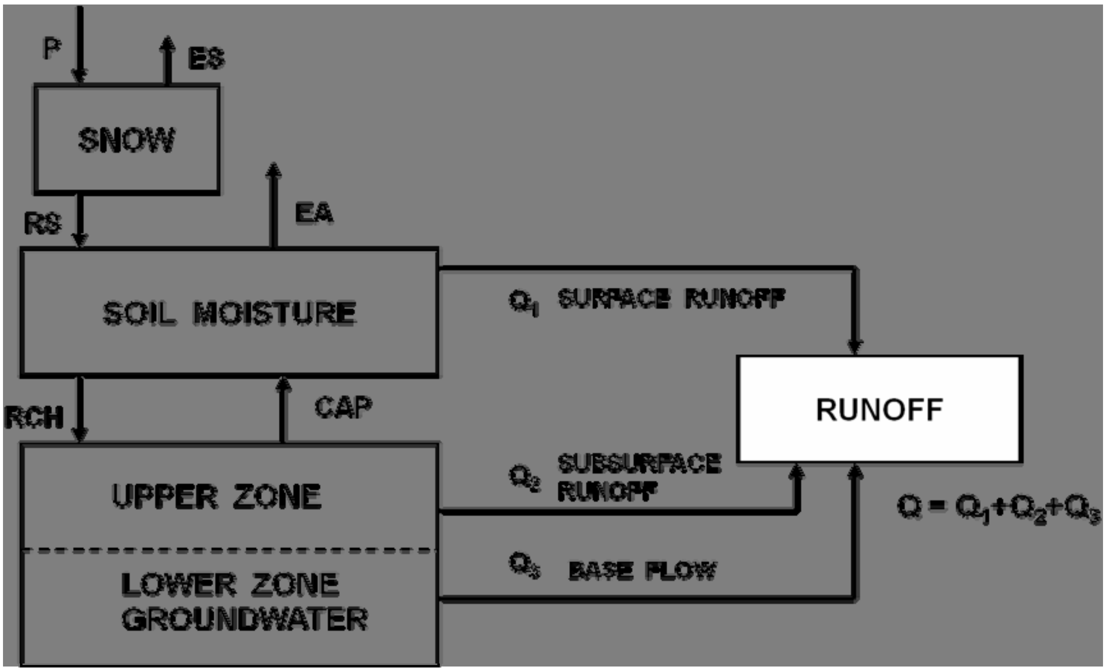

Figure 1. The general structure of the model for the each hydrological response unit (Ziverts and Jauja 1999).
P = precipitation; ES = evaporation from snow; EA = evapotranspiration from root zone; RS = rain and snowmelt water; RCH = recharge to groundwater; CAP = capillary flow.

A principally different approach for the hydraulic routing of the Lake Burtnieks was used. The approach is based on common hydraulic methods of open channel. There was a lacking of channel measurements to obtain discharge rating curve Q=f(H) at the outlet of the Lake Burtnieks. However, Q=f(H) on the bases of the typical parameters of Latvian river channels (Golubovskis 1993) has been calculated.

RESULTS

Results of analysis shows that the numerical values of the model parameters obtained for individual basins mirrors (atspoguļo) the geomorphologic conditions of concrete areas of the basins.

Table 3. The model parameters for basins of hydrological stations

Parameters	Basins		
	Briede- Dravnieki	Seda -Oleri	Rūja – Vilnīši
WMAX	62	64	60
ALFA	0.163	0.170	0.080
ZCAP	143	140	140
A2	0.00063	0.00058	0.00060
DZ	84	81	72
A3	0.00075	0.00074	0.00072
PZ	260	240	260
BETA	2.1	2.1	2.1
KU	0.62	0.63	0.63
KL	0.24	0.28	0.28
KS	0.05	0.05	0.05
CMELT	2.5	2.5	2.5
AMELTK	0.05	0.08	0.08

T1	0.5	0.5	0.5
T2	-0.1	-0.1	-0.1
RCHR	18	16	16
RCHRZ	25	25	25
RCHR2	26	25	25
RCHR2Z	20	20	20
ROBK	1.5	1.5	1.5
WHC	0.1	0.1	0.1
CFR	1.2	1.2	1.2
DPERC	0.0	0.0	0.0

Modelled and observed discharges relations for subbasins are sufficient or even good (Fig.2). For basin Briede - Dravnieki simulated and observed daily discharges correlation coefficient is r=0.919 and Nash criteria R^2=0.829. For basins Seda – Oleri r=0.886, Nash criteria R^2=0.679 and Ruja – Vilnishi r=0.833 and Nash criteria R^2=0.629 where simulated and observed discharges relation is weaker.

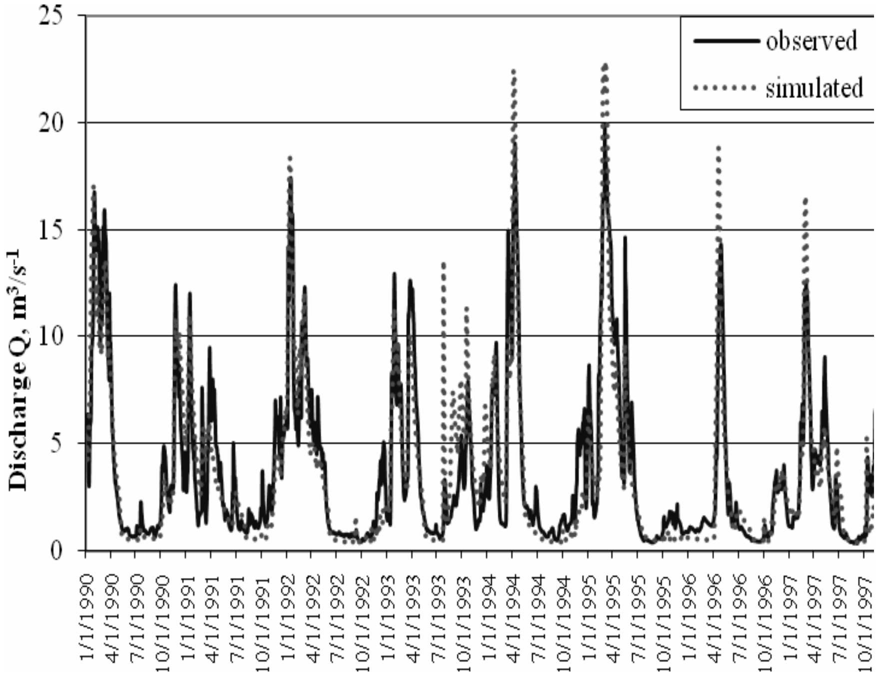

Figure 2. Simulated and observed daily discharge at the hydrological station Briede-Dravnieki

For the basin of Lake Burtnieks and Salaca River basin till Mazsalaca are used values of parameters are shown in table 4. Simulated and observed water levels in Lake Burtnieki for whole 7 years period is sufficient, but relation between simulated and observed discharges in Salaca River – Mazsalaca can be obtained even as very good (Fig.3).

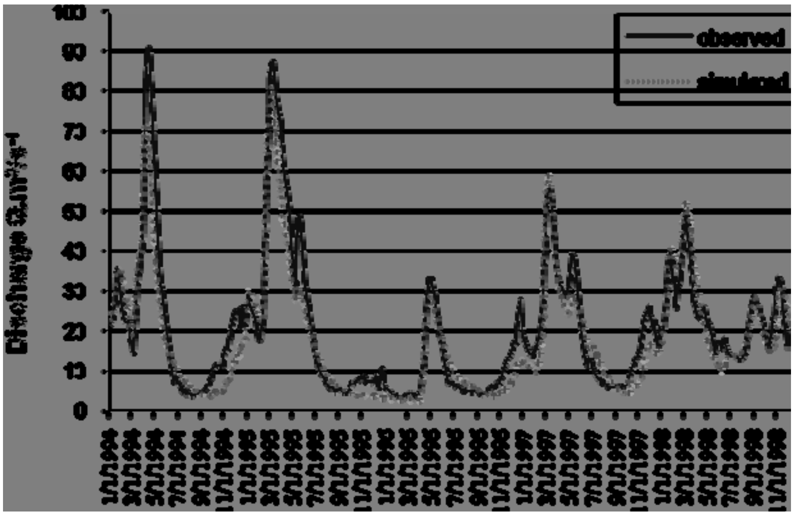

Figure 3. Simulated and observed daily discharge at the hydrological station Salaca-Mazsalaca

Table 4. The model parameters for the River Salaca subbasins

Parameters	Basins				
	Briede	Seda	Rūja	Burtnieks	Mazsalaca
WMAX	62	64	64	62	62
ALFA	0.163	0.170	0.170	0.163	0.163
ZCAP	143	140	140	143	143
A2	0.00063	0.00058	0.00058	0.00063	0.00063
DZ	84	81	81	84	84
A3	0.00075	0.00074	0.00074	0.00075	0.00075
PZ	260	240	240	260	260
BETA	2.1	2.1	2.1	2.1	2.1
KU	0.58	0.59	0.58	0.58	0.58
KL	0.20	0.20	0.20	0.20	0.20
KS	0.05	0.05	0.05	0.05	0.05
CMELT	2.5	2.5	2.5	2.5	2.5
AMELTK	0.05	0.08	0.08	0.05	0.05
T1	0.5	0.5	0.5	0.5	0.5
T2	-0.1	-0.1	-0.1	-0.1	-0.1
RCHR	18	16	16	18	18
RCHRZ	25	25	25	25	15
RCHR2	26	25	25	26	16
RCHR2Z	20	20	20	20	20
ROBK	1.5	1.5	1.5	1.5	1.5
WHC	0.1	0.1	0.1	0.1	0.1
CFR	1.2	1.2	1.2	1.2	1.2
DPERC	0.0	0.0	0.0	0.0	0.0

DISCUSSION AND CONCLUSIONS

The main source of difference between the simulated and observed runoff values is the quality of precipitation input data, as well as the location of the available meteorological stations to characterise the spatial and temporal distribution of precipitation in the drainage basin of Lake Burtnieks. The lowest statistical criterion R^2 0.67 was found for the River Seda. These reasons determine a specific hydrological regime of the River Seda which differs from others. It could be explain by a flat and broad flood plain and a high percentage of the wetlands in the river drainage basin.

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ABSTRACTS

Lake Nasser Flood and Drought Control Project (LNFDC); Implementation of Nile Forecast System (NFS) Capabilities Integrated with Climate Changes Uncertainty

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Quantitative information on water supply, demand and quality is needed for water resources planning. Since planning considers future developments, which are unknown, this requires scenarios of changes supply and demand in which different changes are assumed. Such changes can be the result of changes in natural boundary conditions such as land use and climate but can also results from changes in socio-economic boundary conditions, such as population growth or economic development.

Egypt is a highly arid country. The Nile is the only river in Egypt and provides 97% of the water requirements. The remaining 3% come from ground water and rainfall. So the seasonal and annual fluctuation of the River Nile natural flow may cause tremendous difficulties for a country like Egypt totally depending on its river. Early information about the river flows was always necessary for short term planning to find out policies for facing shortage and drought conditions. In the absence of long-term storage before the construction of the High Aswan Dam (HAD), the situation was more sensitive and vulnerable to extremely high or low floods.

In addition, more water will be needed to fill different growing future demands in Egypt and other Nile basin countries. Competition among increased demands for water could escalate even without climate change. If climate change results in increased warming, droughts, and evaporation, reduced flow in the Nile would further exacerbate Egypt's problems, and the country could face an explosive situation. With respect to Egypt, to explore possible adaptations to the future conditions, the water resources planners want to assess different possible strategies and series of measures to adapt to the future conditions.

To obtain such quantitative information for the water management in Egypt, a chain of mathematical models is needed to describe the processes that determine the water supply to Egypt, simulate consequences of different water demand and make comparison between different options for adaptation strategies.

The Lake Nasser Flood and Drought Control project (LNFDC) is one in a long row of projects carried out at the Planning Sector of the Ministry of Water Resources and Irrigation all focusing on the water management in Egypt and the water supply from upstream Lake Nasser.

With the LNFDC project a complete chain of modeling tools has been brought together at one location, the Nile Forecasting Centre, which can be used for an integrated assessment of various changes in water supply and demand in the Entire Nile Basin. It helps in building up future scenarios to manage effects of foreseen changes in rainfall and evaporation patterns due to climate changes in the Nile basin as well as effects of upstream developments such as water saving projects and irrigation schemes.

The paper gives an overview of the LNFDC/ICC project, its motivation, objectives, methodology, and preliminary outputs. It also focuses on - up to now- gained experiences of the project in assessing the impacts of external changes as climate and upstream developments on water flows, and setting policies and scenarios for future water plans.

ESTIMATION OF THE HYDROLOGICAL IMPACT OF CLIMATE CHANGE IN THE TISZA BASIN WITH SPECIAL EMPHASIS ON FLOOD CONDITIONS

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Abstract: A set of different climate change scenario output resulting from the PRUDENCE project for the Tisza Basin was routed through the complex hydrological modelling system developed at the National Hydrological Forecasting Service, VITUKI. Hadly Centre HadAM3H A2 scenario results received through ETH CHRM and MPI REMO models served as input for the hydrological tools. Daily discharge series were produced for a set of the main hydrological stations of the Hungarian section of the Basin. Control and scenario version output of surface temperature, precipitation and PET were utilized. The validation was carried out based on the period 1984 – 2003 of meteorological and hydrological observations. Monthly and seasonal flow characteristics have been analysed. Alongside with the results of the transient simulations a continuous stochastic simulation model, the hybrid Markov-chain type model developed by Szilágyi et al (2005) to produce climate effect reports for the Upper Tisza basin with special emphasis on flood problems including the interaction of basins of different runoff production significance and the coincidence and superposition of flood waves. Despite the large uncertainty revealed throughout the whole exercise an assumption was made that results may serve as direct or indirect input for water management Decision Support Systems in a region with many transboundary streams. It is expected that further elaborated results could contribute to the implementation of the conceptual plan Improvement of the Vásárhelyi Plan – IVP an important flood protection and complex water management initiative in Hungary.

Use of Statistical Methods to Detect Climate Change and/or Variability in the Upper Blue Nile River

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ABSTRACT

The Blue Nile River (from the Ethiopian Plateau) contributes about 84 % of the Nile water, which is characterized by strong annual cycle and great inter-annual variability, with a dominant peak in August.
The objective of this paper is to apply statistical techniques to detect evidence of climate variability or climate change in the time series of flow and rainfall of the Blue Nile River.

The analyzed series includes rainfall series at (8) rain gauging stations and flow series at Eddeim. The techniques used include trend analysis, Automatic Segmentation of Time Series, Onset, Cessation, and Duration. These methods were applied to total rain, peak flow and time to peak flow.

Trend analysis and annual rainfall showed that there is a statistically significant declining trend. The average Onset of the Rainfall was found to be at dekad 11 (April 11-20) and the average Cessation date was found to be the 28th dekad (October 01–10). Changes were noted on the onset and cessation dates. There is no significant trend in the annual Flow series.

The average Onset of the Flow at Eddeim was found to be at dekad 19 (01-10 July) and the Cessation was found to be at dekad 31 (01-10 November), giving a Duration of 12 dekads of flow. There is no statistically significant trend in the Annual Peaks, and the average time to Peak was found to be 21st of August with standard deviations 13.54 and coefficient of variation 0.06.

The study found that, despite the statistically significant declining trends in the rainfall series and the change in mean flow series, the variations can be attributed to climate variability. There is no evidence of climate change detected within the study period as no systematic prevailing changes seen.

Destruction of traditional agricultural Societies in the coast of Hamoon International Lake

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Abstract

Long ago, Hamoon Lake in the Eastern part of Iran (Sistan) had been the only Fresh-water container with about ambits 400 thousands hectares and 2-5 meter depth. In recent years, this lake is dried because Hirmand river flow from Afghanistan was discontinued.

This lake had always had so many effects in terms of climate, economical and social conditions on the lives of the inhabitants of Sistan region, such as having the role of a cooler whenever the temperature is high in summer, Fishing and Fishermen, and most important of all is the creation of large and small Societies around the coast at the lake. Unfortunately, in recent years, this traditional and international Lake is dried and consequently, the large and small created societies have been vanished.

Farm level water management as an adaptation strategy to climate change

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Climate change is now an acknowledged fact. Irrespective of current mitigation measures, global temperatures are expected to rise in the near future. The definition of sustainable development by Brundtland Commission (1987) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" seems anachronistic. According to the Intergovernmental Panel on climate change (IPPC, 2001), climate change will lead to an intensification of the global hydrological cycle and can have major impacts on regional water resources, affecting both ground and surface water supply for domestic and industrial uses, irrigation, hydropower generation, navigation, in-stream ecosystems and water-based recreation. Even though these statements sound prophetic, most of these changes are already felt in terms of changes in the total amount of precipitation, its intensity, frequency and timing.

Even though long-term goal is to arrest climate change through various mitigation measures, the immediate need is to focus on adaptation and coping strategies to the already changed climatic conditions. The coping capacities of the societies vary with respect to their preparedness. Thus, climate change impacts are going to be most severe in the developing world, because of their poor capacity to adapt to climate variability (Gosain et al.2006).

In India, various water management and livelihood programs are already underway in the form of in-situ water conservation through watershed development programs, diversified income generating options to cope with droughts, crop diversification, conjunctive use of surface and groundwater, flood control and management and disaster management. Improving water use efficiency through conjunctive use of surface and groundwater is an important step. Water saving technologies such as drip and sprinkler irrigation can go a long way in enhancing water productivity. The Government of India is increasingly emphasizing on increasing income and production per drop of water.

Irrespective of various programs and available technologies, when it comes to adoption and adaptation, it boils down to evolving local level plans and management strategies that suit local conditions. The objective of this paper is to establish the conceptual link between the larger global phenomena with the local village level initiatives to adapt to adverse conditions. It also attempts to elucidate the information gap existing between different stakeholders in their capacities to understand implications of local actions from a larger hydrological and climate change perspective.

Identifying the vulnerable areas and communities and involving them in the adaptation strategies assumes priority. It is important to secure the livelihoods of rural poor and vulnerable communities by building and enhancing their adaptive capacity to better cope with adverse impacts of climate change and improve disaster preparedness.

Tsunami And Water related Disaster Mitigation And Climate Change - Issues On Ecological And Social Risk.

Bhole Dr. A.G. * , Dr. LALIT P. CHAUDHARI , Prof.
S. P. Yavalkar. M.D.Shivankar , Dr.A.V.Parwate and others

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Abstract :

South Asia is more vulnerable to Geo disasters and impacts of climate changes in recent years. On 26 December 2004 massive waves triggered by an earthquake surged into coastal communities in Asia and East Africa with devastating force. Hitting Indonesia, Sri Lanka, Thailand and India hardest, the deadly waves swept more than 200 000 people to their
deaths. .More than 20 million population in the Indian coastal region alone and 50 million all over the coastal zones are witnessing the social- economical and ecological risks and impacts due to Tsunami and elated climate changes .

The economic losses to coastal ecosystem, agriculture, irrigation, aquaculture, drinking water resources, coastal industries and infrastructure are very high due to extreme geo-disasters that are linked with environmental and climate changes .The ecosystem, economic system, agriculture and aquaculture system in this region are severely affected and need systematic rehabilitation. Also mitigating the geo-disasters, marine hazards and rehabilitation during post tsunami period , scientific knowledge is needed, requiring experienced research communities who can train the local population during tsunami rehabilitation.

Instutite For Sustainable Development And Research ,ISDR,India; AVCCE, India and International Cmmission on Groundwater and Seawater Interactions ,Switzerland,alongwith Open University Geology Society, U.K. jointly started the initiatives on the problem identifications in management of risks in geo-disasters, tsunami rehabilitation etc., to investigate problems related to social-economic and ecological risks and management issues resulting from the December tsunami and Geo- disaster, to aid mitigation planning
in affected areas and to educate scientists and local populations to form a basis for sustainable solutions.

This presentation reviews the status and issues of ocean –atmosphere interactions, Geo-risks, marine risks along Indian coast focusing on technical issues, biodiversity related problems and damage arising from the tsunami and water related disasters and its impacts on agriculture, aquaculture, irrigation, drinking water, coastal infrastructure, coastal ecosystems and coastal economic systems. This study signifies that climate changes and risk management, Geo disasters and Tsunami education is needed for mitigating potential Geo-marine risks in this region for capacity building for oxygen minimum zones and conservation of coastal ecology based on local resources.

IMPACT OF CLIMATE ON WATER RESOURCES MANAGEMENT IN GEORGIA

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The climate of Georgia is caused by influence of Black Sea, the complex topography prevailing in Caucasus Mountains, and also factors of circulation and radiation. Climate changes influences upon intensity and distribution of a drought on the territory of Georgia. The drought considerably reduces water supply for energy generation and irrigation of agricultural lands located especially in down-stream.

In spite of the fact that water is available during the majority of years and water supply much more below available resources, often there is no qualitative management. In Georgia process of creation of precisely certain strategy of water resources management and integration of various sectors has begun rather recently.

In consequence of deterioration of an infrastructure and occurring changes in management of the basic sectors of water use (agriculture, water-power engineering), efficiency of water use has decreased. Conditions of various sub-sectors are the following:

- The agriculture is the basic consumer of water though these volumes have decreased. Irrigated territories have decreased from 469 000 hectares up to approximately 175 000 hectares. The drained areas have decreased from 163 000 hectares up to 20 000 hectares.
- Water reservoirs provide development of power generation and irrigation of more than 100 000 hectares of arable lands.
- However water basins and dams demand repair, monitoring of water inflow and its discharge has decreased, planning on their operation is not integrated, and not flexible enough for regulation of a problem of shortage of water resources.
- From the point of view of treatment of polluted waters, merely 10 % of industrial runoff and 13 % of sewage are treated, and regulation remains uncertain.
- There is no effective control of an industrial water intake.

Georgia can considerably improve the activity under the reaction upon impact of a drought by means of development of the adjusted management of ecological disasters over the regions subjected to droughts and improvement of water-use sectors.

The worn hydrometeorological observation network should be modernized to do more exact forecasts about weather and availability of water resources, and also to carry out better monitoring of water flowing from the East to the West and corresponding water basins.

It is necessary to improve regional data exchange for reception of better forecasts of presence of water resources in region, and also introduction of preliminary data to the countries which are located in downstream.

Improvement of the river beds, in particular, restoration of irrigational channels of East Georgia where these channels have viable potential in concrete economic conditions and also more effective and rational use of water for irrigation is important.

For maintenance of reliable development of the hydroelectric power it is necessary to improve management and conditions on water reservoirs during the periods of shortage of water resources.

In agricultural sector, Georgia should integrate management of a drought into wider strategy of agricultural development with accent on following measures:

- Improvement of agrometeorological models.
- To strengthen interfarm water resources management
- To improve interfarm technologies, including field tests and demonstration, trainings.

ASSESMENT OF THE POTENTIAL IMPACT OF CLIMATE CHANGE UPON SURFACE WATER RESOURCES IN THE BUZAU AND IALOMITA WATERSHEDS FROM ROMANIA

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The warming of the global climate caused by greenhouse effect can induce essential changes in the hydrological regime and water resources at a different time and space scale.

Water balance modelling with regard to climate change scenarios can give substantial information on changes in the hydrological situation in the future. Water-balance models are especially useful for identifying the regional hydrologic consequences of changes in temperature, precipitation, and other climatic variables.

The aim of the present research is the determination of the impact of possible climatic change in the 21st century upon surface water resources in the Buzau and Ialomita river basins, using the WatBal water balance model.

The analysed river basins covering an area of 14392 km² are located of the outside of Curvature of the Carpathian Mountains, in an area where the altitude varies from 50 m to 2500 m. In accordance with the altitude, the annual precipitation varied from 400 mm/yearin the plain area, to 1400 mm/year in the mountain area and the evapotranspiration between 850 mm/year in the plain area, to 500 mm/year in the high area too. On the other hand, due to a very high variability of weather conditions, droughts as well as excessive humidity periods occur during the year.

WatBal is an integrated water balance model developed for assessing the impact of climate change on river basin runoff. This model has essentially two main modelling components. The first is the water balance component that uses continuous functions to describe water movement into and out of a conceptualized basin. The second component is the computation of potential evapotranspiration. The model input components are: precipitation, air temperature, relative air humidity, wind speed, sunshine duration, net radiation, albedo and historic discharges (only for calibration of model parameters). The output components are: effective precipitation, potential evapotranspiration, total modelled runoff (direct, surface, subsurface runoff and baseflow) and relative depth of water reserves in the basin.

Monthly data series of 7 meteorological stations and 2 runoff gauging-stations on the period from 1961 till 1990 have been used for calibration of the WatBal model in the local conditions of this area.

The values of the modification of the air temperature and precipitation, in the selected analyzed catchments, in the hypothesis of the double amount of the CO_2 in the atmosphere for the reference year of 2075 were determined with the regional climate model RegCM. This model has been used recently to examine climate variations at scales that are not resolved by global models. To the extent that it produces realistic climate simulations, such a model can be a powerful tool in the study of regional climate impacts.

Finally, in the paper, the values of mean monthly discharges at Slobozia gauging station on the Ialomita River and Racovita gauging station on the Buzau River, estimated in above-mentioned hypotheses, are presented.

Impacts of Climate Change on Water Resources of Sri Lanka

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Increasing food production for the growing world population is one of the key challenges for mankind which will require water for irrigation. Anthropogenically induced climate change is expected to influence rainfall patterns, temperature with resulting impacts on evapotranspiration and soil moisture deficits. Global warming will alter water resources and irrigation water requirements, and their distributions in time and space. Planning adaptation requires an understanding of likely spatial variation. Therefore this study focuses on the climate change impacts on soil moisture deficits which will have serious impacts on the water resources.

Climate change datasets for Sri Lanka were derived using outputs from the UK Hadley Centre for Climate Prediction and Research model (HadCM3) for selected scenarios for the 2050s, chosen from the Intergovernmental Panel of Climate Change Special Emission Scenarios Report. A simple water balance method is used to estimate the maximum annual potential soil moisture deficits. A Geographical Information System has been used to model and map the impacts of climate change on rainfall, temperature and soil moisture deficits.

Under the scenarios tested, there will be a slight increase in annual average rainfall because of an increase in rainfall during the south west monsoon. But the north east monsoon rains decrease. Similarly the annual average temperature increases. These changes in rainfall and temperature, together with other climatic factors, would increase the maximum annual potential soil moisture deficit significantly in the dry zone areas, demanding higher irrigation need. The major food production activities in these zones would then be at risk. Previous studies have used the maximum annual potential soil moisture deficit as a climatic indicator to estimate the irrigation need in other countries. Therefore the maximum annual potential soil moisture deficit could be used as a tool to estimate the future irrigation demand in Sri Lanka to design appropriate adaptation measures.

Effects to the Irrigation Requirements and Scheduling of Peaches and Grapes in Southern Ontario, Canada Climate Change

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The objective of this study was to develop and validate an irrigation scheduling model that can reduce risks associated with projected future climatic and hydrologic conditions. Potential changes in climate can impact agriculture and water resources. A changing climate could lead to more drought and alter the water requirements for fruit production. Hence, analysis on the effect of the future climate scenarios on the crop water requirements and the corresponding trends of irrigation needs was the main focus of this study.

Local effects of global warming are difficult to predict with General Circulation Models (GCMs) since they encompass large land areas. However, statistical downscaling of these model outputs can be used to simulate the climate for a specific local area. A Statistical Downscaling Model (SDSM 3.1) was used in conjunction with historical temperature and precipitation data to develop possible climate change scenarios for two fruit producing regions in Southern Ontario, Canada (the Niagara Peninsula and the Lake Erie North Shore). The resulting climate scenarios were input in the CROPWAT, a Food and Agriculture Organization (FAO) developed model for irrigation management. The CROPWAT model can estimate the potential evapotranspiration, an important hydrological component affecting irrigation water demand. As such, the crop water requirements, irrigation schedules, and yield estimates of wine grapes and basket peaches in the region will be determined.

A soil-moisture monitoring device that records volumetric soil moisture data, called capacitance probes (or C-probes) were installed in the experimental sites. Moreover, monitoring of crop's water uptake with sap flow meters were set up simultaneously. With the data on soil moisture condition and soil water uptake, a crop water stress index can be developed, thus, proper irrigation scheduling can be made based on the developed crop water stress index.

The performance of the SDSM model was validated using the 30 years historical data obtained from the closest weather stations of the experimental sites, while CROPWAT model output were evaluated against the data obtained using measurements from the two experimental sites of peach orchards and vineyards in the two regions of Southern Ontario for the growing seasons of 2005 and 2006.

Challenges of River Basin Information System (RBIS) as a Framework for the Assessment and Monitoring of Surface Water in Nigeria

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ABSTRACT

Most developing countries, especially in Africa, have been characterized by poverty and hunger, a situation that has been traced to the daily rapid reduction in the quality and quantity of available water resources. Less than 1% of the global water resource is reliably available for human consumption. A larger proportion of this percentage is polluted in most settlements in the developing nations. This therefore necessitates the call for adequate management of the existing source in these countries. One of the management options is the Geospatial information technology (GIT) as decision support tool in water resources management. Evidently, knowledge of this technology in the developing countries is low. Its application to some human endeavours in these countries is often fraught with some challenges. This paper presents the potentials of adopting the technology in the management of Nigerian surface waters. It envisages that the efficacy of the technology could reduce the present level of slow response to water quality assessment, fund wastage, duplication of duties, and ensure adequate distribution of good water to the people.

Rainwater Harvesting – a solution in cities facing Climate Change

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Key Words : rainwater harvesting, aquifers, adaptation, equilibrium, ecosystems, traditional temperature rise

Introduction : The severe impact of global warming and consequent climate change is conclusively proven through various studies and reports. Historical evidence of harvesting rainwater to mitigate effects of sudden climatic upheavals is found across the world, but especially in South Asia. Analysis of some of these existing systems reveals comprehensive efforts of human adaptation towards threatened environmental unbalance. Modified application of this knowledge in modern civilization can pave the road towards the maintaining of equilibrium in extreme climatic variations. Also, due to unprecedented temperature rise, many low-lying human settlements will be extremely vulnerable to intrusion of sea water and increased salinity of aquifers. As such, rainwater harvesting will be the only hope for dealing with an acute water crisis.

With the release of the extensively researched report of Intergovernmental Panel on Climate Change(IPCC) on February 2, 2007, climate change is proven ‘unequivocally’. The devastating impact of this shift threatens to swallow all facets of human habitation. However, rainwater harvesting (RWH)techniques have been historically utilized to mitigate these effects across the world, much evidence of which exists in South Asia, especially India. From the North Indian state of Jammu to the South Indian state of Tamil Nadu, each region has at least a few surviving examples of RWH systems that illustrate the delicate balance of ecosystems in the face of impending climatic disasters. Unfortunately, huge investments are made on centralized water supply systems which very often fail to deliver but traditional RWH gathers little interest. Understanding these systems will reveal thousands of years of experience and research into physical, economic and social adaptation of human beings towards climate change. Although direct application of these may not be suitable for modern civilization, modified utilisation can have far reaching consequences in the balancing of climatic variations and sustainable paths of growth for the future. It is heartening to note that across many Indian cities, building rules have and are being amended to incorporate mandatory RWH requirements in the design of housing and other projects.

Monitoring water system change under a warming climate

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About two thirds of the water precipitated over land returns to the atmosphere via evapotranspiration. Most of the remaining precipitation water flows eventually from land to sea, transporting with it various dissolved substances and pollutants. Climate change may largely affect the geographical distribution of water and solute fluxes in this system. In addition, human land and water use changes may also have considerable regional to global effects on continental water and solute flux distribution. It may therefore now be even more important than earlier to develop up-to-date and relevant water information systems that can facilitate critical research on water system change in a warming climate.

We identify critical gaps in water system monitoring across various scales, from local through regional to the continental and global scale. On the local to regional scale, monitored areas with regard to water and pollutant fluxes are found to have quite different pressure characteristics than unmonitored areas. This monitoring bias may mislead coastal runoff and pollutant load estimates and is also found on the continental to global scale. On the latter scale, the open accessibility of water and solute flux data has further decreased dramatically for population-rich and thus particularly water-demanding and pollution-producing near-coastal catchment areas.

Land use and cover data are also necessary for independent calculation of evapotranspiration, especially in situations of limited access to direct runoff data. We study uncertainties in these data and associated ET estimations on the global scale and in detail for the African continent. Large parts of Africa are predicted to face severe challenges due to climate-water interlinkages, but the availability of and accessibility to data for increased scientific understanding of these linkages are low. In general our results indicate a strategic need for assessing and optimizing the availability and accessibility of water and land use data, with regard to their costs and benefits on different scales.

Analysis of short-term trends in snow cover variability in the European Alps - based on operational sub-pixel snow mapping with NOAA AVHRR data

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Abstract

In alpine regions such as the European Alps, snow is a predominant environmental factor. High accurate snow monitoring in the Alps is of great importance as temporal and spatial variations in snow coverage have farreaching consequences on the natural and the socio-economic systems. It is required for various purposes such as meteorological modelling, climate studies, snow mapping, estimation of stored water equivalent or snowmelt runoff prediction. The main objectives of this study is to detect temporal and spatial patterns based on the statistical comparison of different sub-pixel classes (class with of approximately 20%) within the Alpine Region.

NOAA AVHRR has been employed for the last 24 years and consequently offers a unique data archive for long-term studies. An additional advantage is the high temporal resolution of NOAA AVHRR, whereas the medium spatial resolution (1.1km at nadir) means a challenge in rugged terrain. The pre-processing of the used data sets includes calibration, atmospheric correction, orthorectification and classification.

Snow classification is done using advanced algorithm to estimate snow cover distribution at sub-pixel scale developed by N.Foppa (2006). The linear spectral unmixing method was applied to estimate snow cover at sub-pixel scale. Principal component analysis, including the reflective part of AVHRR channel 3, is used to detect fractions of snow and no snow within a pixel. Substantially, this algorithm improves the possibility of detecting differences concerning the snow distribution in forested areas, lowest-elevation zones and over complex topography for operational and near-realtime applications(Foppa 2006).

Time series of approximately 7-10 years are used to derive trends in interannual as well as in interregional snow cover variability. In order to benefit form the sub-pixel algorithm, different classes of 20% steps are analyzed for shifts in snow cover distribution. A first application is carried out for the Alps as a whole before proceeding to the analysis of previously designed sub-regions. Qualitative and quantitative shifts in snow cover distribution become evident as the frequency distribution of the sub-pixel classes varies over time and space.Finally, a temporal comparison of distinct north-south profiles further supports the assumption of an elevation dependency of changes in snow cover dynamics. In contrast to conventional in situ snow observations, remote sensing data regularly provide spatial snow cover information. Moreover, fractional snow cover maps provide even more detailed information and therefore improve the accuracy of the statistical analysis of snow cover variability. The results presented in this study are based on a short-term analysis and give an overview on possible climatic changes in snow dynamics over the past decade. Further studies aim to link shifts in snow cover distribution to trends in climatic parameters such as temperature and precipitation. However, in order to line out any trend related to snow cover development, more years need to be processed and analyzed. Nevertheless, the climate sensitivity of the alpine snow cover has to be emphasised, making it a supplement to current climate change indicator systems. This study may contribute to more accurate prediction of potential effects of human activities on natural resources in the alpine environment.

THE TELECONNECTION BETWEEN THE EXTREME PRECIPITATION IN SERBIA AND THE NORTH ATLANTIC OSCILLATION (NAO) AS WELL AS ARCTIC OSCILLATION (AO)

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Abstract

The paper describes the analysis of the North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) influence on the precipitation regime in Serbia. NAO is one of the most significant teleconnection patterns on the northern hemisphere and AO is its complement. The cross-correlation of NAO Index with few climate parameters in Serbia has already been proofed for the period 1951-1996. in winter. The Influence of NAO on climate elements in Serbia in winter period (December-March) is significant, indeed. The following correlation values were obtained between NAO Index and: pressure 0.60, temperature 0,64, both for Belgrade, while negative cross-correlation was obtained for precipitation –0,53.

However, this paper focus on the precipitation distribution analysis, only. Data from 21 stations in Serbia for the period 1951-2005. in winter have been analysed. The teleconnection between the AO and precipitation regime in Serbia, are analysed for the first time in this paper.

The methods used are the Empirical Orthogonal Function (EOF) creating the regionalisation maps of the precipitation field in Serbia. The cross-correlation analysis for the evidence of the teleconnection patterns has been applied, too.

A special attention, with respect to International Polar Year (IPY) is devoted to the winter precipitation extremes and links with AO.

The peculiarities of water regime of oligotrophic bog and its influence on runoff from bogged basin of the Kluych river

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Research of water regime of bogs is very urgent at the present especially under conditions of modern strategy of peat bogs rational use. As it is known, the territory of the West-Siberian Plain is characterised by a great number of bogs (they take almost 27 % of this area). Many rivers in this area start from water-dividing bogs. Water regime of bogs determines the regime of bogged runoff and represents itself a natural change of bogs water level and moisture reserves of active bog layer in time and place. Changes of water regime depend on a parity of elements of bog water balance. We view the peculiarities of water regime of oligotrophic bog herein.

Water regime observations were carried on in main biogeocenoses (high riam, low riam, sedge-sphagnum swamp) of water-dividing oligotrophic bog with central- oligotrophic development stage within the limits of a basin of the Klyuch river (the north-east spurs of the Vasyugan bog).

Water regime is characterised by sharp raise during spring, steeples abatement disturbed by precipitations, low summer-autumn mean water and raise of level during autumn rain period. Raisey of level, according to the researches of the chair of hydrology of Tomsk State University, was 25 cm on average during the period since melting of snow until high water peak. During high-water years, the level of bogs is very high due to abundant water being received from melted snow during spring as well as from summer rains. The activity of spring levels abatement differs in biogeocenoses from 1 cm /day in the center of the bog and up to 4 cm/day on the periphery. During 1998-2006 the following bog levels were observed: in high riam – (-26 cm), in low riam – (-2 cm), in sedge-sphagnum swamp - 0 cm from average bog surface. The highest levels were observed in high water year (2002): 7, 17 and 12 cm upper the average bog surface correspondently. Absolute minimum of levels during the observation period (2003) comprised: high riam – (-71 cm), low riam – (-40 cm), sedge-sphagnum swamp - (-18 cm). The fluctuation of levels by space of oligotrophic bog is synchronic. Fluctuation amplitudes are somehow different between every biogeocenoses that is connected with condition differences under which their water regime is being formed. It is observed regular decrease of amplitudes and increase of water bog levels from periphery to the center of the bog. Average amplitude of levels comprises: in high riam – 35 cm, in low riam – 21 cm, in sedge-sphagnum swamp – 14 cm. In some years, the amplitude can reach 62, 53, and 29 correspondently. In the whole water regime of the researched oligotrophic bog is a regular and characteristic one for this type of bogs that are in great abundances in West Siberia and in European area of Russia.

Fluctuations of level of water bogs determine the water content of the bogged basin of the Kluych river in spring. Especially close connection of the river runoff and levels of bog waters is observed when high water decreases. When the level decreases to the lower limit of the active horizon their connection with river runoff is absent. On average, the volume of the Klyuch river runoff during high water period was 62 mm.

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Climate patterns associated with high and low river flow across the northern North Atlantic region

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To assess the sensitivity of high and low river flows to climate change and variability, improved understanding is needed of contemporary associations between large-scale climate variation and hydrological response. This is particularly important for the northern North Atlantic region, as high latitude areas such as this are predicted to be especially vulnerable to climate change. Furthermore, despite increasing interest in the apparent correlation of atmospheric circulation patterns with river flow (such as the North Atlantic Oscillation, NAO), relatively little is known about the processes underpinning such statistical hydroclimatological relationships across the northern North Atlantic region (defined here as encompassing northern Europe and northeastern North America). To address this research gap, composite analysis of large-scale climatic controls on high and low monthly river flows for the period 1968-1997 is performed. High and low flows are focused upon because these often have the greatest hydrogeomorphological, ecological and socio-economic impacts. As an organisational framework for the analysis, composite analysis is performed on a regional basis, with regions of similar inter-annual river flow variation identified using hierarchical cluster analysis.

Composite analysis shows that the occurrence of high and low flows across northern Europe is linked to geopotential height variation in the Azores High and Icelandic Low. From November to April, this variation is consistent with a positive correlation of the NAO and river flow. River flow in northeastern North America is more closely associated with the East Coast pressure trough. In November, the geopotential height patterns associated with high and low flows for northern European and North American flow regions are consistent with opposing influences of the NAO (positive for northern Europe and negative for North America). These, are accompanied by contrasting precipitation anomalies between northern Europe and North America. An inverse relationship between large-scale climate and river flow is also found between northern and southern regions in northern Europe. This occurs in April, May, and from July to November, and appears to be influenced by the physical barrier of the Norwegian mountains and their effect on the passage of weather systems across Scandinavia. During November, this inverse climate-river flow relationship is also linked to the Scandinavian atmospheric circulation pattern.

These newly defined spatial patterns in river flow and associated atmospheric drivers help define the climate drivers of high and low river flows across the northern North Atlantic region. Furthermore, the apparent NAO and Scandinavian pattern signals in river flow suggest that these modes of variation may provide potentially powerful analogues for identifying how predicted changes in large-scale atmospheric fields will downscale to regional river flow variation.

HYDRODYNAMIC AND VULNERABILITY OF WATER RESOURCES IN TROPICAL URBAN ZONES: CASEOF MINGOA WATERSHED (YAOUNDE-CAMEROON)

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Keywords:
underground hydrodynamic, Mingoa, pollution, protection zones, vulnerability, water resources.

ABSTRACT

The Mingoa watershed is one of the twenty five catchments found in Yaoundé. A study gearded at understanding hydrodynamic phenomena and the vulnerability of water to pollute in Yaoundé town was realised in this watershed. The study revealed that the hydrodynamic activity in this watershed is directly linked to pluvial fluctuations. The hydrodynamic map of the upper layer of Mingoa watershed reveals two types of flow: convergent and divergent with main drainage axes of global orientation NE – SW, SE – NW and N – S permitting the definition of favourable sites for implantation of underground water. The potentials sources of pollution listed are numerous and varied (latrines, damages sewage treatment station, a lack of clean-up infrastructures, wild rubbish heaps). Results of physico-chemical analyses permitted to notice that apart from temperature, hydrogen potential (pH) an free CO_2, values of others parameters are well – centred on the norms of water quality destined to human consumption as prescribed by the World Heath Organisation (WHO). However, the values of ammoniacal nitrogen (from 0,67 to 4,65 mg/l), of faecal streptrocoquos (from 48 to $5{,}80 \times 10^5$ UFC/100 ml) and faecal coliforms (from 300 to $1{,}07 \times 10^6$ UFC/100 ml) are largely greater than the threshold values required by WHO and permitting to conclude that theses waters are polluted and strongly forbidden to human consumption.

Thanks to data resulting from simulations and different laboratory analysis, the dynamics of contamination of superficial and underground water naps in fractured cristalline zones are densely populated was posed. Two protection zones with radii of 10 metres and 20 metres respectively can be envisaged around the water points in order to permit the soil to fully play its purification roles. Adequate measures (sensibilisation, establishment of protection zones, etc.) have to be taken in the Mingoa watershed and beyong, through out the town of Yaoundé in order to face the very advanced degradation of water resources, and this, despite socio-economic and land constraints which constitute the main obstacle to this dynamic.

Impact of Hydro Power Station activity to river's hydrological regime in Estonia

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The paper presents results of evaluation of influence the small-sized Hydro Power Stations (HPS) activity to hydrological regime of rivers in Estonia. Hydropower has played an important role in sustainable energy development in Estonia. Thus more than 700 HPS were in operation at the begging of XX century. However, only the Narva HPS worked after 1960s. During the recent 15 years more than 30 HPS were reestablished and have caused significant adverse impact to hydrological regime of river. However, the legislative standards and rules for regulation of HPS activity are not issued so far in Estonia.

Existing hydrometric stations below hydropower facilities are frequently damaged due to either too much water or its scarcity. The data from Roostoja, Tõrva, Räpina monitoring stations was used for the analysis. The statistical methods for estimation for river runoff for flood and low-flow periods were used for the assessment of impact of HPS stations to hydrological regime. The low-flow period is the most sensitive for operation of HPS. During this period in same cases the operations of HPS lead to violation of environmental flow even to its absence and consequently to negative impact to water environment.

The main objective of the study was to analyze the river runoff before and after of HPS reestablishment, in order to provide the decision makers with reliable information, which is essential during consideration of a new environmental act.

The result of the analysis emphasizes some problems and shows necessity in providing of additional guidance for protecting and improving water resources. Its may require modifications in HPS facilities and flow regime regulations to achieve such purposes as sustaining fisheries or maintaining riparian vegetation.

Impact of Climate Change on Low Water Conditions in the River Rhine Basin and Implications for Adaptation Strategies for Inland Waterway Transport

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Abstract

There has been a marked progress in recent years in investigating the impact of climate change on hydrology and to some extent on selected sectors of water resource management. Many of these studies are concentrated on the River Rhine basin. Nevertheless, a review of the actual state of scientific findings distinguished in statistical analysis of observed climatic and hydrological data, the development and interpretation of regional climate scenarios, and an assessment of changes in the discharge regime as well as in the occurrence of hydrological extremes by use of hydrological models reveals that large uncertainties exists, still. These can be partly referred to the uncertainty which is inherent within natural systems, the uncertainty of the future socio economic conditions as well as to uncertainties which can be attributed to the modelling chain used for delineating climate change and discharge projections. Navigation on inland waters is sensitive to changes in discharge and water levels especially with regard to long-lasting low flow conditions. Therefore, adaptation to climate-induced changes should be taken into account as one of several challenges for long-term inland water transport. Although, water resources management as well as the related branches of economy are customised in doing decision making under great uncertainty climate change forms a new challenge in finding appropriate adaptation strategies. The potential as well as possible limitations of available regional climate and discharge scenarios for supporting these issues will be discussed with special emphasis to low water conditions of the River Rhine and concepts of possible adaptation strategies applicable for inland water transport.

Possible Way of Precipitation (Rivers Runoff) Regime Assessment of the Middle Asian Region under Climate Changeability

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Uzbekistan is situated in the region of Central Asia and is characterized by Turan type of climate, that is a variety of subtropical climate.

The main water resources of the region appeared to be the runoff of the rivers with snow-glacier alimentation. Thus, the river runoff is mainly determined by atmospheric precipitation fall within the cold period of a year. Such regime of precipitation fall is typical for subtropics.

In the middle of the last century synoptical processes observed in the region had feen described. The connection of weather conditions in the region with synoptical processes was presented in climate aspect (dynamic meteorology). On its base Kozik E.M. showed the possibility to use methods of genetic and dynamic climatologies when describing hydrology of the region, that was done by Shultz V.L.

Further the possibility of hydrological forecasts on the base of synoptical ones was shown in the works by Aksarin N.N.

Presently the work is finishing, in which the possibility is proved of the determination atmospheric precipitation fall season in different parts of the Middle-Asian region using metheds of genetic and dynamic climatologies with due regard for physico-geographical medium of the region.

The account of physical models of fronts and cloud layer on the base of dynamic meteorology method allows determination (estimation) of the seasonal regime of atmospheric precipitation fall: the beginning, the end, its intensity and also, as a whole, the duration of the processes of precipitation fall in the region.

The next stage of researches taking into account the climatic factors, being outward with respect to the region will enable us to define numerical indecies of the regime of atmospheric precipitation fall regime more accurately. That, in its turn, will enhance our opportunities to study climate changeability impact on the regime of atmospheric precipitation in the Middle-Asian region.

Impacts of climate variability and change on economic development in Africa

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To achieve the Millennium Development Goals (MDG's) significant economic growth is needed in many developing countries. It is estimated that to reduce poverty by 50% in 2015, a 7% GDP growth per year is necessary in most African countries. Most of the people living in poverty are from rural areas and depend on dryland Agriculture for their livelihood and the future development of these rural areas depends heavenly on water. Water availability is usually related to rainfall and due to significant climate variability in many developing countries water availability is often unpredictable. Both insufficient rainfall (droughts) and too much rainfall (floods) can have significant impacts on development.
We used a database with 23 years of data on annual rainfall and total GDP and Agricultural (Ag-) GDP growth for sub-Saharan African countries to analyse the impact of climate variability on development. In most countries (Ag-) GDP growth was much higher during years with above median rainfall compared to dry years. Results of a panel data analyses showed that GDP growth is highest during years with slightly above average rainfall. Both dry and very wet years reduce economic growth. However the negative impact of dry years is more severe than the impact of wet years.
Climate change scenarios project that rainfall variability will probably increase and the average rainfall is likely to change. Using a range of scenarios (with more variable and/or more or less rainfall) we studied the impacts of future climate change on GDP growth. A more variable climate (50 increased standard deviation of annual rainfall) can potentially reduce economic growth by 35% in Sahel countries and by 20% in countries in East Africa and Coastal West Africa. Also a reduction in rainfall can have severe impacts on economic growth. A 10% lower rainfall can reduce GDP growth by 12% in Southern Africa and up to 40% in the Sahel countries. A combination of lower and more variable rainfall has the potential to reduce GDP growth to near zero in several African countries. A small increase in rainfall of 10 to 20% can potentially improve GDP growth due to a lower number of dry years.
If African countries want to achieve the MDG's and realise a steady economic growth it is necessary that countries become less vulnerable to climate variability. The first step to climate proofing development should be including the risks of climate change and variability into plans on development and achieving the MDG's. In addition, a range of structural and non-structural measurers is necessary. Structural measurers would include dams, dikes and reservoirs where non structural measures would focus on early warning, spatial planning, and living with water strategies.

The Major Water Issue of the Lower Volga Region: Runoff Regulation or Adaptation to Its Changes?

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The Volga River basin is characterized by the area of 1.4 mln km^2 that equals to 13% of Europe. Currently, it features vast climate changes relevant to runoff fluctuations of the Volga River and its tributaries. In the 20th century, the range of long-term Volga River discharges (150-380 km^3) was practically equal to its average value (240 km^3).

During 1937-1978, construction of artificial water reservoirs cascade (165 km^3 total volume) and hydroelectric power stations/ HEPS (11,225 MWt total capacity) changed completely the natural hydrological river regime, mainly due to interannual runoff redistribution. Its volume decreased 1/3 during the flood period, while in winter it tripled. Decrease in the flood length and volume lead to reduced natural reproduction of commercially important fish species and agricultural areas subjected to floods. These losses were previously envisaged as non-recurrent.

Nevertheless, the semi-centennial experience shows that combination of natural runoff fluctuations and cascade reservoir functioning makes hydrological flood regime persistently unfavorable for fisheries and agriculture in the Lower Volga region. These economies are notably sensitive both to the volume and time flood parameters.

Two approaches are proposed for sustainable functioning of regional water-dependant economies: regulation of water discharges from reservoir cascade and adaptation of economy system to hydrological fluctuations. Currently, the first approach is prioritized, however, its specific implementation does not always consider for the runoff stochastic.

Meanwhile, analysis of runoff changes and their natural fluctuations shows that discharge regulation capabilities are limited as regards water balance in reservoirs, both during low and high water (e.g., shipping, coastal inundation, etc.). In theory, feasible runoff regulation may be improved by enhanced forecast timing and precision as referred to the Volga-Kama cascade inflow during the flood period. Six-month-ahead forecast may be used for both interannual and yearly water flow distribution. Currently, one-month-ahead flood forecast is only justified for the Lower Volga region.

Under these conditions, another approach gains importance. It is aimed at adaptation of regional economy to fluctuating hydrological conditions with consideration to appropriate replacements, i.e., hatchery versus natural fish reproduction, and artificial irrigation instead of natural watering.

With the purpose of obtaining state financial support for adaptation program, state income of (1) electric power production&sales at the Volga River HEPS and (2) transportation fees (the Volga River waterway) is proposed to be used; feasible partnership of water-power and transport companies is strongly encouraged. The Lower Volga water issue should be considered as a reflection of general problem dealing with water use dependent both on climate change and anthropogenic factors. The regional experience reveals synergic increase of economy dependence on climate change, specifically in the areas concerned with water utilization.

The challenge is whether we are to strengthen further this dependence through rising anthropogenic load on aquatic basins or we should free from it through adaptation of economy to climate-related changes in water resources. Our studies show that the second path is more preferred.

An Assessment of the Climate Change Impact on Food and Water Security in India

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Finding adaptive mechanisms for the possible impacts of global climate changes is a global challenge, especially to low-income countries like India with fast rising population. Population of India has crossed one Billion and is still rising and is expected to stabilise only by the year 2050 at 1.5 Billion. By that time demands in food and water will be tremendous. Indian economy and life of majority of population largely depends on agriculture, the largest consumer of water. Water resources in India are being fast deteriorated and depleted because of pollution, overuse and misuse. In addition to the shrinking area of agricultural land due to encroachment and land degradation, the fertility of soil is also decreasing due to over use of fertilizers and over irrigation that leads to salinisation, adding to the concern over food security. Any extremes in climate or a considerable change in rainfall seasonality would affect the water availability and food production and this would result in catastrophic effect in India. This paper is an assessment of the possible impact of a climate change on the food and water security in different parts of India in near future. Extremes in rainfall amount and seasonality have been analysed and changes in water availability in an altered climate, as predicted by climate models have been estimated for different zones using water balance model and the impact on food production has been assessed, considering the population increase and associated needs, study reports of national and international agencies and the typical socio-economic conditions in India that influence the agricultural sector. Shifts in regional climate have been examined to assess the influence of local climate systems on the regional hydrological conditions. Results show that the water availability will be drastically reduced in most parts of India and this will definitely affect food production in near future. Regional climate shifted to drier or wetter categories on many occasions during the last century. Extreme climate, especially the trends towards high seasonality in certain parts may disrupt the balance in water availability and food production and this may have fatal effects on all facets of life. Falling water availability always leads to conflicts over allocation. India urgently needs to develop an appropriate management strategy and an updated policy for food, water and environment. Policy should be effectively implemented to conserve and properly manage water, to control land and water degradation and to resolving social issues like water disputes and negligence to farming sector due to diversion from traditional jobs. This is possible with a strong and impartial political will. Guidelines for efficient management and for an appropriate better policy have been provided, taking into consideration the economic, social and environmental conditions.

Climate change and water resources: risk and risk management-Guyana

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Abstract.

A major consequence of climate change is rise in sea level. The consequence of such rise can be severe on coastal aquifers and rivers, both on continental coastal areas and small oceanic islands.
Guyana is situated on the North Eastern coast of South America, has an area of 215,000 square kilometers, a population of about three quarters of a million people, more than ninety percent of whom reside on a narrow strip of the coastland, less than ten kilometers from the ocean. The coastland is below high tide level of the Atlantic Ocean, is extremely flat, and is protected by a system of dykes, mainly of concrete and clay.

A large number of large rivers flow South to North into the Atlantic Ocean. Water supply for domestic, agricultural and industrial uses are obtained from a combination of ground and surface water sources. In this paper an attempt is made to analyze situations that can arise as a result of sea level rise. A specific sea level rise of one meter by the end of the century and the impacts of this rise on the water resources is investigated. The results indicate that the consequences for the surface water resources can be severe, but not as severe for the ground water resources.

Predicting the Impacts of Climate and Land Use Change on West Bank Rainfall

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The West Bank rainfall regime is characterized by high spatial and temporal variability which influences strongly where and when recharge occurs over the West Bank aquifers. A good quantitative description of the space-time variability of rainfall is therefore crucial to the planning and management of groundwater resources. Recently, an extensive study of West Bank rainfall was carried out as part of the SUSMAQ (Sustainable Management of the West Bank and Gaza Aquifers) project.
A key objective of this work was to try to quantify the impacts which climate change might have on West Bank rainfall. . Current predictions from General Circulation Models (GCMs) are for significant decreases in annual rainfall over the region by the 2050s. This would be combined with an increase in temperature, causing higher losses from evaporation and changes in snow accumulation and melt. However, GCMs typically operate with grid sizes of 300x300km, and so GCM rainfall scenarios for future climates must be downscaled to the spatial scale at which recharge occurs. To enable this to be achieved in SUSMAQ, a downscaling methodology was developed which linked two stochastic rainfall models operating at different time and scale scales. The first model was a multi-site point rainfall model operating at an annual timescale which could reproduce the interannual rainfall variability characteristic of the West Bank. The second model enabled spatial rainfall fields with a grid resolution of 1 km and a temporal resolution of one day to be generated. By suitably combining the rainfall outputs of the two models, all the characteristics of observed rainfall which are important for modelling recharge could be reproduced satisfactorily.

However, when the HadCM2 GCM rainfall outputs were analyzed for the present climate, it was found that they had major deficiencies in terms of reproducing the seasonal and spatial characteristics of the regional climate, and therefore the GCM future rainfall scenarios could not be used as a basis for downscaling. A higher resolution version of the HadCM2 model (PRECIS) was implemented on a PC as part of SUSMAQ with the aim of (a) improving the simulation of the regional climate, and (b) investigating the possible impacts of the large scale water transfers from the north of Israel to the south, and the associated extensive irrigation of the arid land there, on the regional rainfall regime. However, it was found that the outputs of the PRECIS model still reflected the shortcomings of the boundary conditions of the larger grid scale HadCM2 model, and so the results could not be used for predicting reliably the impacts of climate and land use change on rainfall. Nonetheless, the stochastic rainfall models can still be used for sensitivity studies and risk analyses of the effects of temporal and spatial rainfall variability on recharge and the sustainable yields of the West Bank aquifers.

ADAPTATION STRATEGIES RELATED TO WATER MANAGEMENT
An Example of the Situation in Southern Europe: a case study of Portugal

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ABSTRACT

The water resources sector is one of the most important domains when addressing climate change. Climate change has direct impacts on the availability, timing and variability of water supply, and these impacts have profound implications on many sectors of our society. Water is used for human consumption, industrial purposes, irrigation, power production, navigation, recreation and waste disposal, as well as for the maintenance of healthy aquatic ecosystems. Its availability and the occurrence of extreme events like floods and droughts condition the location of cities, industrial and agriculture areas, power generation plants and trading centres.

Adding to these direct impacts of climate change on water resources, there are the indirect impacts, those derived from changes in economic and social activities which may lead to new pressures of the water systems, namely a water demand increase, a pollutant load increment or a significant change in the way we use our land and distribute our activities. These indirect impacts may also affect our capacity to satisfy water needs and to protect humans and its activities, while protecting and promoting the quality of the water bodies and the health of the aquatic ecosystems.

Southern Europe, namely Portugal, Spain and Italy, will be the countries mostly affected by climate change. Based on the results of the SIAM project (SIAM meaning Scenarios, Impacts and Adaptation Measures) which studied several integrated scenarios of the impacts of Climate Change on Water Resources, Agriculture, Forest, Biodiversity, Energy, Health and Tourism, the paper provides a brief survey of the impact of climate change on the Portuguese water resources, showing significant regional asymmetries within the country. In general terms this aggravation of the impacts is expected from the Northern region of Portugal, with Atlantic influence, towards the South, with Mediterranean characteristics.

The impacts scenarios are the base for the discussion on the need for adaptation. Regardless of the success in reducing emissions, humankind will have to cope with some degree of climate change, and if a consistent and coherent set of actions is planned ahead it can significantly minimize the potential costs and suffering associated with climate change.

To deal with the complexity of the impacts of Climate Change in water resources, an interdisciplinary approach is required which must cover all sectors of our society. The point is made that the challenge of climate change must be integrated in the overall policy and planning strategy on water resources. The adaptation strategies on water resources must be defined at a basin scale and involve all stakeholders. It must include supply-side actions to increment and diversify water sources and demand-side actions to limit the growth and, if possible reduce, the pressures on water resources. In addition it must also address more general issues related to economic, social and institutional planning, development, land use and wealth enhancement.

At a time where all European Member States are engaged in preparing their River Basin Management Plans, under the guidance of the Water Framework Directive, the point is made that Climate Change should be considered as much as possible at all stages of this major planning effort. The adaptive approach of the WFD enables a phased integration of relevant adaptations, as knowledge and practices

become available, with the aim of reducing vulnerabilities and increasing resilience to environmental, social and economic problems arising from climate change.

A preliminary description of the foreseeable adaptation strategies and measures in what concerns water management in Portugal is provided. The current national policy on water resources and the major ongoing programmes in this domain are presented and their ability to address climate change impacts is discussed. The need for new programmes and measures is emphasized and some preliminary ideas are discussed.

Groundwater abstraction and climate change - impacts on physical habitat conditions for brown trout (*Salmo trutta*) in a small Danish stream

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Abstract

According to the European Water Framework Directive, Danish streams are to achieve good ecological status (GES) before 2027 and GES has to be assessed in relation to reference conditions often estimated from undisturbed or past conditions. The now acknowledged global climate change will increase temperatures and potentially affect both the amount and seasonality of precipitation in Denmark. It is expected that annual precipitation will increase but summer precipitation will decrease. These changes will in turn decrease summer discharges, increase water temperatures and potentially have severe impacts on ecological conditions in streams. At present groundwater abstraction has great impact on streams in the eastern part of Denmark. This is causing reductions in discharges during summer and is having great impacts on the ecological conditions in the streams. Therefore, the combination of groundwater abstraction and climate changes will potentially have severe impact on stream ecosystems in the eastern part of Denmark.

This study focused on estimating groundwater abstraction impacts and reference conditions for stream discharges and in-stream physical habitats for brown trout (BT) (*Salmo trutta*) in a small stream in the eastern part of Denmark. Stream discharge was simulated using a NAM rainfall-runoff model and reference discharge condition was assessed by omitting groundwater abstraction from the model setup. In-stream physical habitat conditions were simulated using the RHYHABSIM habitat hydraulic model. By combining simulations of stream discharge and in-stream physical habitat modelling, present and reference physical habitat conditions was assessed and compared. In addition, future (2071-2100) stream discharges were assessed using the NAM-model with inputs of precipitation, evaporation and temperature data which were adjusted to future climate conditions (IPCC A2 scenario) using average monthly correction values for precipitation and temperature. Simulated future discharges were combined with simulations of the physical habitat to assess the future physical habitat conditions for BT.

It was found that groundwater abstraction had the largest relative impact on summer discharges and the largest actual impact on winter discharges. Simulations of the physical habitat revealed highest potential for BT fry and least for adults in accordance with previous studies of the stream. The combined discharge and physical habitat simulations suggested that adult BT was relatively most affected by groundwater abstraction mainly due to a lack of suitable water depths. Summer water temperatures and dissolved oxygen (DO) turned out to be limiting factors for the dispersal of BT in parts of the stream. Consequently water temperature and DO affected the relation between simulated physical habitat and observed biological conditions. This stresses the importance of including other parameters than traditionally used in habitat hydraulic modelling. The simple assessment of the future physical habitat conditions suggests that BT will be slightly impacted by the changes in discharge caused by climate change. The assessment did not include the effects of increased water temperature on the conditions for BT in the stream. In addition to decreasing summer discharges, increasing water temperature could have severe negative impacts on conditions for BT.

In relation to this study, a new Danish research project has started with the overall goal to develop an integrated hydrology-habitat assessment system which includes the capabilities to describe effects of climate variation, land use and groundwater abstraction on ecological conditions in Danish streams.

The present and future of water resources in Slovakia

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In Shiklomanov work (International Conference on Water and Environment. Development issues for 21st century, Dublin, Ireland, 1992. Keynote papers.) available water resources for central Europe are declared as follows (in $m^3.10^3$/year/inhabitant):

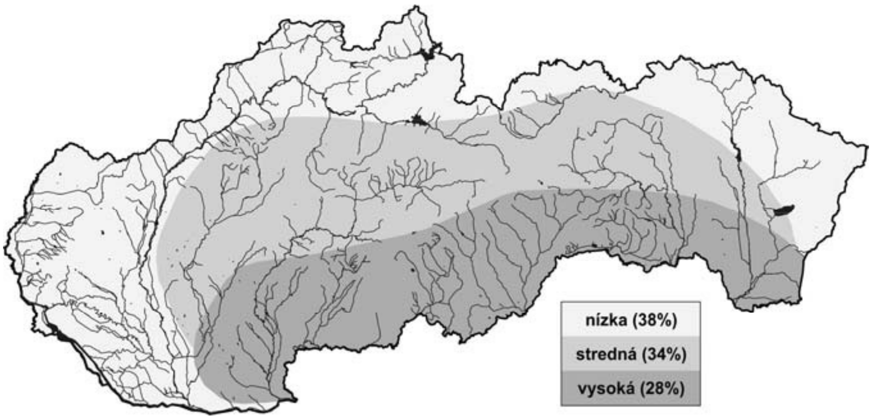
1950	1960	1970	1980	2000
3,0	2,8	2,6	2,4	2,3

In Slovakia the similar results have been reached. Meanwhile Shiklomanov value for 2000 is estimated, all values in below table are results of regular monitoring.

1931-80	1981-94	2000	2001	2002	2003	2004	2005
2,84	1,93	2,36	2,37	1,97	1,29	1,85	1,91

In period 1931-80 the significant climate changes are not assumed. This period is considered as the 1st reference period in Slovak hydrological practise. In 1981-94 in Slovakia relatively long dry period has been recorded. The year 2003 has been recorded as an extraordinary dry (historical has been more dry as the recorded year 1947). We can see that after the year 1980, the values of available water for various periods and individual years has reached lower values that Shiklomanov has estimated for central Europe.

The changes of the water resources should gradate and differently for 3 selected regions:



The most significant changes should be reached approximately on 28% of Slovak area.

As an important tool for assessment of water resource utilization in Slovakia the Water Resource Balance of The Last Year is used. The available water resources and realized usage (according the valid permissions and reporting duty of realized water usage for water users) in monthly step are balanced. The gap of available water resources is equated with amount of realized utilization in 137 profiles of all key streams of Slovakia. According to the ratio of this difference and the limit MQ, (limit for biological balance of streams) 3 classes of water-resource balance are possible to reach. We propose, that in the future with decreasing of available water resources the increasing of the MQ limit is essential issue. This issue will cause the increasing the number of occurrence of passive water resource balance. To prevent the negative status of the water resource balance the water resource measures are needed. This expected development can cause reduction of water consumption which was in fact in the past not needed.

EXTREME DRY WEATHER INTERVALS OF THE GROWING SEASON IN VOJVODINA PROVINCE

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A method of describing and analysing the stochastic process of droughts is presented in this paper.The droughts are defined presently as the upper extremes of intervals of no rainfall and are treated as a random number of random variables in an interval of time [0,t]. All important components of extreme dry weather intervals such as their duration, time of occurence, their total number in a given time interval [0,t], the longest drought duration in a given time interval [0,t] and its time T (t) of occurence are taken into consideration. The basic assumption of the method is that the extreme dry weather intervals are independent, identically distributed random variables and their occurence is subject to the Poisson probability law. According to the theory of supreme of random number of random variables, the explanation and analyses of the largest rainfall deficit and largest drought is obtained by the Zelenhasic- Todorovic method for given location. The investigations are carried out for the part [0,t] of the year which is equal to the growing season, because it is of prime importance for agriculture, although the method can be applied for the entire year or part of it. Application of the method is performed on the records of meteorological station Rimski Sancevi in Vojvodina Province, Serbia. Good agreement between the theoretical and empirical distribution function for all analysed components of the process of extreme dry weather intervals is found.

GEWEX Water and Energy Budget Studies

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During the past several years, the Global Energy and Water-Cycle Experiment (GEWEX) Continental Scale Experiments (CSEs) began an attempt to develop the “best available” description of global and regional atmospheric and land water and energy budgets. Since few regional or global hydrometeorological observations were available when these water and energy budget studies began, initial studies mainly included global and regional atmospheric analyses along with macroscale hydrologic models. Fortunately, a number of observationally based GEWEX data sets have since become available and include: the Global Precipitation Climatology Project (GPCP) precipitation, International Satellite Climate Comparison Project (ISCCP) and Surface Radiation Budget (SRB) radiation, the Global Runoff Data Center (GRDC) runoff. Other globally gridded observations sets are also now available. We have therefore begun to compare the National Centers for Environmental Prediction / National Center for Atmospheric Research (NCEP/NCAR), NCEP / Dept. of Energy (DOE), European Centre for Medium Range Forecasts (ERA40), and Japanese Meteorological agency reanalyses, along with the Global Land Data Assimilation and Global Soil Wetness Project output to these observations in order to assess our current uncertainty to characterize and close continental-scale water and energy budgets. As will be shown, the closure errors are not small. Individual process errors in these models, which tend to cancel, are likely much larger. For example, analysis precipitation errors are likely balanced mainly by evaporation errors. Errors in other hydrometeorological processes, such as regional runoff and moisture convergence, are almost as large, especially for certain regions like the Amazon and GAME tropics.

Evaluation of the impact of climatic change on water resources of Alcanadre basin, Ebre river, using hydrologic models and GIS

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Keywords: GIS-BALAN, hydrologic model, climate change impacts

ABSTRACT

This paper presents the evaluation of climate change impacts on water resources in Alcanadre Basin, in Ebre River. The calibration period was defined as the hydrological years of 1970 to 2000. Simulation period was defined between the hydrologic years of 2070-2100. Projections outputs of CGCM2, Global Climate Model, for IPCC A2 scenario were used. GENBALAN was developed for statistical downscaling of CGCM2 monthly results to simulation periods and posterior disaggregation of monthly to daily series.

The projected decrease in annual average precipitation in Alcanadre basin was 20.7%. The projected increase in annual average temperature was 3.69ºC. The semi-distributed hydrological model GIS-BALAN was used to perform water balance in the selected basins. Firstly the model was calibrated with the flow measured period, calibration period, of 1970 to 2000. In general, the fit between measured and computed streamflows in annual and monthly scale was excellent. For the most part the fit between daily measured and computed streamflows was good. Hydrological components were highly affected. Simulated streamflow under climate change decreased about 50%. The impact of climate change on water resources is projected to be more intense in summer periods than in winter periods. That could acute current waste deficit problems in the water availability in dry periods.

Water, Energy and Climate: Greenhouse Gas Emission from Hydropower Reservoirs

dos Santos Marco Aurélio [1], Luiz Pinguelli Rosa[2], Bohdan Matvienko[3], Ednaldo Oliveira dos Santos[4], Carlos Henrique Eça D´Almeida Rocha[5], Elisabeth Sikar[6], Marcelo Bento Silva[7], Ayr Manoel P. B. Junior[8]

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Dams produce biogenic gases through decomposing organic matter under water. Some of these gases are effective in terms of global warming such as methane, carbon dioxide and nitrous oxide.

Gas fluxes from the hydro reservoirs are measured in Brazil since 1992 although additional studies are required to establish a better level of knowledge of this matter, while also reducing the uncertainties inherent to the findings available to date.

To estimate the GHGs emissions from hydro reservoir it is necessary a better knowledge of the carbon cycle in the reservoirs, before and after flooding, at various levels (reservoir level, watershed level and after dam impoudement).

The main mechanisms of carbon transportation in the watershed and at reservoir are:

- Gas fluxes of CH_4 and CO_2 trough diffusion and bubbling from the lake surface to the atmosphere;
- Leaching of organic carbon (dissolved and particulate) from the soils of watershed to the tributary rivers;
- Carbon fixing by photosynthesis;
- Decomposition of pre existing biomass at the botton of reservoir generating CH_4 and CO_2 to the water;
- Carbon fossilization in the sediment at the botton of reservoir as humic compounds.

The dam impoundment changes the carbon movement by flowing much slower than the original river. This new condition favors the establishment of phytoplankton and nutrients increase in which methanogenesis replaces the oxidative water generating biogenic gas production.

To determine accurately the net emissions caused by hydroreservoir formation is required significant improvement of carbon budgets studies on different representatives' hydro reservoirs at tropical, boreal, arid, semi arid and temperate climate.

At the same time is needed an intercomparison of various GHG measurements and analysis techniques in terms of their accuracy and representativity. Additional research should be organized on a worldwide basis, including scientist and technicians with wide international representation.

GHG emissions from hydro reservoir are a subject of extreme strategic importance and comparisons with other types of electric generation like as thermopower should be required.

Variations in Extreme Daily River Discharge across Russian Arctic Drainage Basin

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Abstract

Daily discharge records from a new data set of 139 Russian gauges in the Eurasian Arctic drainage basin with watershed areas from 16.1 to 50 000 km^2 were analyzed for signs of change in maximum and minimum daily river discharge. Our results suggest that for these basins relatively equal numbers of significant positive and negative trends in maximum daily discharge are present, which draws into question the hypothesis of an increasing risk of extreme floods. A significant shift to earlier spring discharge, which is consistent with documented changes in snowmelt and freeze-thaw dates, was also observed. Spatial analysis of changes in maximum discharge and cold season precipitation revealed consistency across most of the domain. Although we observe regional changes in maximum discharge across the Russian Arctic drainage basin, no evidence of wide-spread trends in extreme discharge can be assumed from our analysis.

We also note a consistent increase in minimum daily flows (or “low-flows”) throughout the Russian Arctic. These increases are found in summer as well as winter, and in non-permafrost as well as permafrost basins. A subset of 12 complete river discharge records from 1935-2002 suggests that recent minimum-flow increases since ~1985 are largely unprecedented in the historical record, at least for this small group of stations. If minimum-flows are presumed sensitive to groundwater and unsaturated zone inputs to river discharge, then the data suggest a broad-scale mobilization of such water sources in the late 20th century. We speculate that reduced intensity of seasonal ground freezing, along with precipitation increases, could drive much of the well documented but poorly understood increases in river discharge to the Arctic Ocean.

Snow and Snowmelt Runoff in Small Catchments in North-western Russia as Changing in Space and Time

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Key words: Snow, Snowmelt, Spatial variability, Interpolation, Trend, Spring runoff

Abstract

Climate-related variability in snow cover has been revealed by long-term observations at Valday, north-western Russia. There appeared decreasing snow water equivalent (SWE) and the mean snow melt intensity along with highly variable, generally increasing liquid (rainfall) precipitation during snow melt period. Problem has been highlighted on how to validate the satellite-based observation data, and what is to be assumed as the ground truth data. Two techniques were developed to advance analyses of the snow survey data: (1) kriging, a variance of optimal interpolation, improved with allowance for elevation gradient and (2) statistical description of the distributions along with landscape analysis. Among other things, these methods are to be used for retrieval of the snow cover spatial distribution at different scales. Reported also is upon two applications aimed: (1) to improve snow melt flow prediction and, (2) to simulate local snow distribution in cold and mountainous regions. Spring discharges from two small rural catchments (one forested and one open area) have been analyzed to reveal trends and regional relationships between SWE, melt water infiltration and spring runoff.

IMPACT OF RIVER FLOW REGULATION ON LAND DESERTIFICATION IN DELTAS

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Keywords: desertification, river basin, deltas, soil, flow regulation.

Abstract

Large-scale irrigation in the river basins of arid and semi-arid regions and reservoirs construction causes strong environmental changes in deltas. They include water inflow reduction, landscapes desertification, groundwater table lowering, and soil salinity increase. Hydromorphic soils lose their fertility. Such a situation takes place in the deltas of large rivers in Central Asia (Syrdarya, Amudarya, Zarafshan, Chu, Ily Rivers), in Mesopotamia (Euphrates and Tigris Rivers), in eastern China (Huanghe River) and in south-eastern Asia (Gangues River and others). Desertification processes in deltas manifest themselves also in Australia (Murray River), North America (Colorado River), South America and in Africa (Nile River and others).

Detailed research in the Ily River basin (Kazakhstan) have shown, that irrigation of 300,000 hectares in the middle reaches decreased the water flow into the delta by 3 km3 and stimulated desertification processes on the area about 800,000 hectares. A productivity of hay lands decreased from 2.0-2.5 t/ha (dry matter) till 0.7 t/ha on desertified soils and till 0.3-0.4 t/ha – on salt-effected desertified soils. Soil desertification and vegetation changes occur for the period from 10-12 till 13-15 years. Solonchaks area in the delta, deprived a vegetation, increased for this period till 200,000 hectares. About 500-700 t of salts from every square kilometer of that area are carried off by the wind on the adjacent territory. Even more dramatic changes of landscapes took place in the delta of Syrdarya River. Irrigation of about 3 million hectares of soils in the upper and middle parts of the river basin caused landscapes desertification processes in the all lower part of the basin, especially – in the ancient (Kzylorda) and present (Kazalinsk) deltas. For the period 1965-1991 area of hydromorphic landscapes decreased in the ancient delta by 500,000 hectares and in present delta – by 400,000 hectares. About 250,000 hectares of rich meadow were transformed into barren solonchaks. Strong desertification processes in other river deltas we observe also at space images.

On the results of our research of soil desertification we have detected ecologo-genetic evolution series which may serve as a scientific base for ecological and soil reclamation-related predictions.

Water withdrawal for irrigation in river basins of arid and semi-arid zones should be confined and balanced with ecosystems needs in deltas to avoid landscapes desertification and ecosystems destruction.

Snow-forest interation in the mixed forest of northern Hokkaido, Japan

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Abstract

Evaporation of snow intercepted by the forest canopy is an important component of the water and energy balances in forests seasonally covered with snow. Knowledge of the snow interception and evaporation processes in forest canopies is important for our understanding of the water cycle in forested areas.

In the present study, we examined the influence of canopy snow on water and energy balances above a mixed forest in the Uryu Experimental Forest of Hokkaido University of Japan during winter 2003–2006. Measured data comprised eddy covariance fluxes above the forest, micrometeorological data, and snow monitoring data obtained from snow weghing lysimeter and by photograph. The quantity of canopy snow strongly influenced the thermal regime of the canopy environment.

Feeding of carnivorous zooplankton in West Greenlandic waters

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The main background for the enhanced research activity in the Arctic during the last decades is the uncertainties about the effects of an eventual global warming. The Arctic marine environment is vulnerable to impacts of human activities and is of high climatic sensitivity. In the Arctic, greenhouse warming over the next century is predicted to be 2-4 times higher than at lower latitudes. A number of models predict that effects of global warming will reduce and thinning the sea ice cover of the Arctic Ocean˙ This will change the water balance in i.e. the North-Atlantic Ocean and potentially have consequences for the production of deep water and thus change the global currents. A change in duration and cover of the Sea ice might also have a large local implication for the region, that today are ice covered, e.g. because it will reduce the salinity in the surface water and consequently enhance the stratification of the water column as well as enhance the growth season for primary producers, and this will change the basis of the marine food webs.

The West Greenland society is almost entirely dependent on marine resources for economical as well as subsistence utilisation. Today, the West Greenland marine ecosystem sustains fisheries which contribute 95% of Greenland's total export value. Knowledge about the marine food webs that supports these rich resources is essential to manage the economical important fisheries resources in a sustainable manner

Increased human impact on marine ecosystems combined with effects of global climate change stresses the need for a sustainable ecosystem-based management. Today, knowledge of the marine food webs in the artic is relatively fragmentary. Important and common predatory groups, such as the chaetognaths and carnivorous copepods are particularly understudied in the Arctic. Consequently, the knowledge base for a proper ecosystem management is inadequate. The large dominating copepods *Calanus finmarchicus*, *C. glacialis* and *C. hyperboreus* are the main food source for numerous species of fish, birds and whales. The understanding of their mortality is therefore crucial. Important and common predatory groups, such as the chaetognaths and carnivorous copepods are particularly understudied in the Arctic. A thorough understanding of the dynamics of Artic food webs is a principle key to enable accurate predictions of global warming on marine food webs and manage sustainable fisheries.

The aim of the present talk is to contribute to a better knowledge about carnivorous zooplankton, their trophic role in artic pelagic ecosystem, with emphasis on their predation on *Calanus* spp.. The diet and vertical and horizontal distribution of the carnivorous copepods and chaetognaths were investigated in west Greenland waters during the Arctic spring. Feeding by the carnivorous copepod *Pareuchaeta norvegica* was assessed by measuring egestion of faecal pellets and the chaetognaths were analysed for gut contents. Simultaneously, prey composition and vertical distribution will be determined and used to estimate predation pressure and selective feeding. *P. norvegica* was at all times restricted to the deeper parts of the water column while the chaetognath *Sagitta elegans* was found at all depths.

Development of Hydrological Regime Monitoring Under Conditions of Climate Anthropogenic Change

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Republic of Uzbekistan is the main user of water in the Central Asian region. Changeability of water resources amount is rather great. Interchange of the periods with wet and dry years is observed in the regime of water objects.

In the thirties of the last century V.L.Shultz had distinguished zones of runoff formation (mountain heights) and of runoff dissipation (plains) on the territory of Central Asia. Exploitation of water resources became one of the main runoff transforming factors. Rational use of the runoff aiming the stable economic development resulted in need of regular hydrological regime monitoring of water objects.

Monitoring of hydrological regime of water objects is developing in Uzbekistan from the beginning of the last century. A significant contribution to hydrological network development has been made by many scientists and practical hydrologists of the region.

At present the work is carried out on preservation and development of the network. Measures are taken for modernization and substitution of traditional devices by modern equipment with partial automation of the routine processes of observation. Programmes have been created on automation the processes of hydrological network observation materials preparation to printing.

Futher development of researches and works will allow ensuring of the stable development of hydrological regime monitoring of regional water objects, automation of the processes of observation programmes and receiving and transfer of hydrological in formation and also of preparation the issues of the State Water Cadastre for publication.

Changes in Ice Regimes of Rivers in the European Russia

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Abstract

The problem of the assessment of ice regimes changing under the influence both the current and future changes of climatic situation is urgent for the rivers of the European Russia. Many mid-size and large rivers within these territory are used intensively during winter time and such ice regime characteristics as dates of ice-on and ice-off, duration of ice events, and maximum ice cover thickness are very important and often limiting factors. Dates and duration of ice events are associated with navigation and specific features of hydraulic structures construction in winter. The ice cover thickness is a determining factor to estimate the ice-bearing capacity and dates of ice-routes operation across rivers. During the last 20-25 years ice regimes in the rivers of Russia were subject to significant changes mainly caused by a stable positive trend of winter air temperatures on the background of the rise of mean annual air temperature typical of most of the country.

Analysis of ice events dynamics in the rivers of the European Russia has been made with the use of observation data series on ice regimes and ice cover thickness published in hydrological yearbooks. Data from 65 hydrological stations installed on large and mid-size rivers within the European Russia have been used for the analysis.

Two methodological approaches have been applied. The first approach is based on a comparison of averaged characteristics of ice regimes for 1950-1979 and 1980-2000 to determine the gradients of these changes during the last two decades .The second approach is based on the establishment of relationships between ice regime characteristics and winter air temperatures for the period 1950-1979. and using these relationships for ice regime assessment for the period 1980-2000. In most cases both of these approaches were used for the analyses. Close results obtained during computations of ice characteristics changes for 1980-2000 by both approaches were used as basis for making principal conclusions and recommendations.

It has been established that dates of ice-on on the largest rivers of the European Russia were 2-6 days earlier if compared with the period 1950-1979. Besides, dates of ice-off appeared to be earlier, too. Mean ice cover duration in the last twenty years in large rivers of European Russia became 2-10 days shorter, if compared with the previous 30-year period. The maximum ice cover thickness on the rivers on the European Russia during the last 20 years was thinner by 2-7 cm on the average. Moreover, a positive tendency towards a thinner maximum ice cover thickness on the rivers of Karelia and Baltic Sea Drainage was observed for the whole 50-year period, whereas changes in the maximum ice cover thickness during 1950-1979 on the rivers of the North East of the European Russia were insignificant.

The above changes in ice regimes on the rivers within the European Russia require an adaptation of different economic branches related with water use in winter time.

A Structured Process for Helping Water Utilities Consider Climate Change

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Drinking water utilities in the United States are beginning to seriously consider what climate change might mean for their ability to provide reliable, clean, safe, and inexpensive water to a growing customer base. The American Water Works Association Research Foundation (AwwaRF), the National Center for Atmospheric Research (NCAR), and the Stockholm Environment Institute (SEI) have worked together to develop a framework around the Water Evaluation and Planning (WEAP, http://www.weap21.org) tool. The approach is described and case study utilities across the US presented.

The sustainability aspect in water resources management on a local scale

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Slovenia annually receives 1500 mm of precipitation in average, however vegetable and fruit production could be affected almost every year by the unfavourable distribution of precipitation during vegetation period. To ensure a reliable and economically feasible plant production with steady quantity and quality of products, irrigation is needed as a supplementary measure.

Studies for Slovenia show temperature increase between 0.5 °C and 2.5 °C by the year 2030, by the year 2060 for between 1 °C and 3.5 °C. Little less reliable are forecasts for annual precipitation amount, the range of the expected change varies from +10 % to –30 %. Summer precipitation amount will most probably decrease for 20 %. A study for fruit orchards in Vipava Valley in West Slovenia using step scenarios, where moderate temperature (+1.5 °C) and precipitation variation (+/- 10 %) was considered, showed that irrigation demand would increase on all soil types. The increased need irrigation was clearly shown for including, and possibly even more severely expressed, on soil types that normally provide sufficient water supply for plant production.

To ensure conditions for intensive agricultural production in Vipava Valley storage lake was constructed during the years 1986 to 1989 to provide water for 3 500 ha of arable land. The construction of large storage lake in West Slovenia at the end of the 80ies was outset for more systematic approach to irrigation, evolving from program developed on the national level with general review of the state's needs and conditions for irrigation. Irrigation is one of the important measures for sustainable land use, which is facing not only climate change but pressures from global economic trends, EU common agricultural policy, urbanisation and other sector policy areas as well.

Throughout the time after the construction the water from the storage lake has been used for application in agricultural sector, either for frost protection or for irrigation. The paper presents overview of the water consumption from the storage lake since its construction, water distribution patterns and subsequent irrigation scheduling. Considering precipitation trends, increasing irrigation demand and tendency to apply some unsustainable practice regarding production, technology and land use, agricultural production in Vipava Valley could be facing water shortage. The paper presents suggestions and opportunities for sustainable water use.
