EEA Report | No 2/2009

Water resources across Europe — confronting water scarcity and drought

ISSN 1725-9177

European Environment Agency

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Cover design: EEA
Cover photo © Stock.xpert
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Layout: EEA/Henriette Nilsson

Luxembourg: Office for Official Publications of the European Communities, 2009

ISBN 978-92-9167-989-8
ISSN 1725-9177
DOI 10.2800/16803

Environmental production
This publication is printed according to high environmental standards.

Printed by Schultz Grafisk
— Environmental Management Certificate: ISO 14001
— IQNet — The International Certification Network DS/EN ISO 14001:2004

— Quality Certificate: ISO 9001: 2000
— EMAS Registration. Licence no. DK — 000235
— Ecolabelling with the Nordic Swan, licence no. 541 176

Paper
RePrint — 90 gsm.
CyclusOffset — 250 gsm.
Both paper qualities are recycled paper and have obtained the ecolabel Nordic Swan.

Printed in Denmark

EMAS
Verified
environmental
management
REG.NO. DK-000244

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Executive summary

Despite the vast amount of water on the planet, decades of unsustainable management mean that water shortages have reached crisis point in many regions. Globally, humans appropriate more than 50 % of all renewable and accessible freshwater, while billions still lack the most basic water services (Pacific, 2009).

Until now, most Europeans have been insulated from the social, economic and environmental impacts of severe water shortages. But as demand increases and the global climate changes, is Europe becoming more susceptible?

The balance between water demand and availability has reached a critical level in many areas of Europe, the result of over-abstraction and prolonged periods of low rainfall or drought. Reduced river flows, lowered lake and groundwater levels, and the drying up of wetlands are widely reported, alongside detrimental impacts on freshwater ecosystems, including fish and bird life. Where the water resource has diminished, a worsening of water quality has normally followed because there is less water to dilute pollutants. In addition, salt water increasingly intrudes into 'over-pumped' coastal aquifers throughout Europe. Climate change will almost certainly exacerbate these adverse impacts in the future, with more frequent and severe droughts expected across Europe.

Key drivers of water use

Addressing the issue of water scarcity requires not only a quantitative knowledge of water abstraction by each economic sector but also a strong understanding of the driving forces behind it. Critically, it is only by changing these driving forces that more sustainable management of water can be achieved.

In the EU as a whole, energy production accounts for 44 % of total water abstraction, primarily serving as cooling water. Twenty-four per cent of abstracted water is used in agriculture, 21 % for public water supply and 11 % for industrial purposes. These EU-wide figures for sectoral water use mask strong regional differences, however. In southern Europe, for example, agriculture accounts for more than half of total national abstraction, rising to more than 80 % in some regions, while in western Europe more than half of water abstracted goes to energy production as cooling water. These sectors also differ significantly in their 'consumptive' use of water. Almost 100 % of cooling water used in energy production is restored to a waterbody. In contrast, the consumption of water through crop growth and evaporation typically means that only about 30 % of water abstracted for agriculture is returned.

Agricultural water use across Europe has increased over the last two decades, driven in part by the fact that farmers have seldom had to pay the 'true' cost of water. The Common Agricultural Policy (CAP) bears part of the responsibility, having in some cases provided subsidies to produce water-intensive crops using inefficient techniques. Recent reforms of the CAP have, however, reduced the link between subsidies and production from agriculture. In general, agricultural water use has now stabilised across Europe but at a high level. Demand for energy crops, however, has the potential to increase agricultural water use still further in future years.

A range of factors influence public water demand, including population and household size, tourism, income, technology, and consumer behaviour such as buying bottled mineral water. In addition, 'leakage' in the distribution and supply networks plays a key role in determining the amount of water reaching domestic premises. Public water supply in eastern Europe has declined since the early 1990s due to the introduction of metering and higher water prices. Recent economic growth in eastern Europe is, however, predicted to reverse the overall downward trend in the future. A similar but less marked reduction in supply is apparent for western Europe over recent years, driven by the implementation of water saving measures.

Tourism can markedly increase public water use, particularly during the peak summer holiday months and especially in southern European coastal regions already subject to considerable water stress. In addition to using water for food, drinks and personal hygiene, tourism is associated with activities such as swimming and golf (because of the requirement to irrigate courses) that significantly increase water use. In southern Europe, tourism has helped to drive an increase in the use of public water in recent decades.

The abstraction of water for industrial use has decreased over the last 15 years, partly because of the general decline in water-intensive heavy industry but also due to technical developments such as on-site recycling of wastewater. Abstractions for use as cooling water have also decreased, primarily due to the implementation of advanced cooling technologies that require less water.

The case for demand-led water resource management

Traditionally, the management of water resources across Europe has focused on a supply-side approach. Regular supplies of water have been ensured using a combination of reservoirs, inter-basin transfers and increasing abstraction of both surface water and groundwater. The nineteenth and twentieth centuries, for example, were characterised by a rapid growth in the number of large reservoirs. Currently about 7 000 large dams are to be found across Europe, with a total capacity representing about 20 % of the total freshwater resource.

Problematically, the historically disproportionate emphasis on supply provided no incentive to limit water use in any sector, leaving the major driving forces of use unchanged. As a result it has promoted the excessive abstraction currently observed in many parts of Europe and the associated harm to aquatic habitats. Continued expansion of supply is not, therefore, a viable management option in the future, particularly given the anticipated increase in the frequency and severity of droughts across Europe.

Europe needs a sustainable, 'demand-led' approach to water resource management, focusing on conserving water and using it more efficiently. Integral to this is a more equitable approach to water abstraction that addresses not only the requirements of competing economic sectors but also the need for healthy freshwater ecosystems. Successfully achieving demand-led water management across Europe will both address the need to adapt to climate change and contribute to lower energy consumption because water and energy use are closely linked.

The need for a more sustainable and integrated approach to managing water resources in Europe is already reflected in water-related policy and legislation. The Water Framework Directive, for example, requires the 'promotion of sustainable water use based on a long-term protection of available water resources'. The European Commission also recognised the challenge posed by water scarcity and droughts in a 2007 communication, which outlined the severity of the issue and presented a set of policy options focused on demand-side management to address water scarcity and drought across Europe.

Demand-side policies and practices

Achieving sustainable water resource management will require the implementation of a number of policies and practices, including water pricing, efficient use of water, awareness raising and tackling illegal water abstraction. The EU and its Member States can play crucial roles in these policy areas, using public spending and grants to create and maintain necessary infrastructure, promote technological innovation and incentivise behavioural change. As such, many of the tools and approaches outlined below could feature as elements of the 'Green New Deal' programmes of public investment that some Governments are considering in response to the current global economic downturn.

This counts in particular for:

- facilitating appropriate water pricing across all sectors, including the implementation of metering to support volume-based charging;
- ensuring that agricultural subsidies are linked to more efficient water use;
- investing in new technologies to increase water use efficiency and upgrading water infrastructure networks;
- focusing investment on the sustainability of alternative water sources where demand measures are already fully exploited.

Water pricing is a key mechanism to achieve more sustainable use of water across all sectors. It is also fundamental to the Water Framework Directive's requirement that the pricing of water services reflect their full costs. To optimise the incentive for efficient use of water, pricing must be tied to the volume of water consumed. In this respect, metering plays a key role and must be implemented across all sectors. Successful water pricing will require a good understanding of the relationship between price and use for each sector.

Irrigated agriculture is central to the local (and in some cases national) economy in many parts of Europe. In some areas, ceasing irrigation could lead to land abandonment and severe economic hardship. Adopting a sustainable and efficient approach to agricultural water use is critical, therefore, not only to protect the environment but also to ensure agriculture remains profitable. Central to this, therefore, is a key requirement that national Governments invest in technologies and measures that improve the efficiency of water use by agriculture.

Various practices can be implemented to ensure that agriculture uses water more efficiently. These include changing the timing of irrigation so that it closely follows crop water requirements, adopting more efficient techniques such as using sprinkler and drip irrigation systems, and implementing the practice of deficit irrigation. In addition, changing crop types can reduce water demand or shift peak demand away from the height of summer when water availability is at a minimum. As with other water saving approaches in agriculture, providing advice, information and education to farmers will enhance their impact significantly. Both national and EU funds, including those disbursed under the CAP, can potentially play an important future role in financing measures to reduce agricultural water use.

Illegal water use, particularly for agricultural purposes, is a major problem in certain parts of Europe. Addressing the issue is a difficult but necessary political and technical challenge. It first calls for the detection of illegal abstraction sites, potentially followed by fines or penalties as a deterrent and subsequent surveillance.

Introducing energy crops should not lead to an increase in water use, particularly in areas of water scarcity, but should instead serve as an opportunity to reduce agricultural water demand. In this respect, energy crops that have a low water demand or are drought tolerant are clearly preferable to the current first generation energy crops.

Modern domestic appliances and fittings are much more water efficient than their predecessors, implying the potential for future reductions in demand from the public water supply. Increasing the use of these modern technologies across Europe remains a challenge, however, and both higher regulatory standards and improved consumer awareness have to play a role in this respect. Leakage of water from supply systems is substantial in parts of Europe and detection needs to be improved, leakage rates accurately quantified and networks upgraded.

Achieving more sustainable use of public water supplies will depend strongly upon raising public awareness of water conservation issues. Various means are available to inform domestic, business and tourist water consumers. They include websites, school education programmes, local authority leaflets and the mass media. Eco-labelling of appliances and eco-certification of, for example, tourist hotels can also play an important role in raising awareness, helping consumers to make informed choices about water efficiency and conservation. In some areas of Europe, lack of water will begin to affect the tourism sector adversely unless more water efficient practices are implemented soon.

Significant potential remains for greater implementation of water efficient practices in industry. Recycling of industrial wastewater has an important role to play in this respect, not only in reducing water use but also the subsequent discharge of wastewater.

Opportunities to expand supply sustainably

Demand-side measures based on conservation and improved efficiency represent the optimal approach to water resource management across Europe. In some regions where this approach is fully adopted, however, demand may still exceed availability. Only in such cases, following the 'water hierarchy' approach of the water scarcity and drought communication, can alternative sources of water supply be drawn on, provided this is done so sustainably. For example, the use of treated municipal wastewater is currently low throughout Europe but could expand significantly, particularly for the irrigation of crops and golf courses, provided that guidelines and standards are adhered to. In addition, both harvested rainwater and greywater from baths, showers, washbasins and the kitchen can be used for non-potable purposes such as the watering of gardens and toilet flushing.

Desalination — the process of removing salts from brackish and sea water — has become a fast growing alternative to reservoirs and inter-basin transfers, particularly in coastal areas of the Mediterranean.

Numerous desalination plants are either being built or planned in Europe, including one that will supply freshwater to London. Energy consumption and the generation of brine are major environmental drawbacks but the practice may be preferable to further depletion of freshwater resources. Decisions on the suitability of future desalination plants need to be made on a case-by-case basis. In particular, the use of renewable energy to power the desalination process and sustainable disposal or subsequent use of the brine produced must be addressed, taking into account all environmental aspects and long-term economic and technological investments.

Initiatives to deepen understanding of the issues

Moving towards sustainable water resource management requires that reliable and up-to-date information is available at appropriate spatial and temporal scales across Europe. Such information has many benefits including providing an improved overview of the causes, location and scale of water stress; helping identify trends; facilitating the evaluation of measures implemented to address unsustainable water use; and assisting EU citizens to engage in water issues.

Information is required not only at the river basin scale but also, critically, on a monthly or seasonal basis, since annual averages are unable to convey fully the peak levels of water stress — normally experienced during the summer months. Unfortunately, the data so far provided to Eurostat and the Organisation for Economic Co-operation and Development (who together organise the collation of data that has enabled pan-European assessment to date) has not been at the optimal spatial or temporal scale. In addition, national assessment and monitoring programmes frequently possess significant information gaps and are seldom harmonised in terms of the type of data collected and the methods employed.

The recently established joint reporting initiative of the EEA, Eurostat and the European Commission aims to address these shortcomings, improving water information Europe-wide and therefore supporting the follow-up process of the European Commission's 2007 communication on water scarcity and drought. Member States will voluntarily submit regular data on both water availability and multi-sectoral water use. This information will be generated at a harmonised river basin scale and on a seasonal basis. While potentially presenting a challenge for Member States' environmental and statistical reporting bodies and their interaction with the relevant sectoral authorities, the initiative is crucial to achieve pan-European assessment of water resources.

In a related development, the EEA has also begun to develop river basin scale water balances for Europe based on the United Nations system of environmental-economic accounting for water. The approach can use both measured and modelled data and will provide accounts on a monthly basis, therefore reflecting water stress throughout the year. The water account methodology is also able to distinguish the impact of water abstraction on observed water availability from that of drought. Moreover, it quantifies the relative contribution of each sector to total water use providing a framework for economic analysis of water management.

1 Introduction

1.1 Background

European citizens do not suffer from the devastating water shortages and poor water quality experienced in other regions of the world. In general, water is relatively abundant with a total freshwater resource across Europe of around 2 270 km^3/year. Moreover, only 13 % of this resource is abstracted, suggesting that there is sufficient water available to meet demand. In many locations, however, overexploitation by a range of economic sectors poses a threat to Europe's water resources and demand often exceeds availability. As a consequence, problems of water scarcity are widely reported, with reduced river flows, lowered lake and groundwater levels and the drying up of wetlands becoming increasingly commonplace. This general reduction of the water resource also has a detrimental impact upon aquatic habitats and freshwater ecosystems. Furthermore, saline intrusion of over-pumped coastal aquifers is occurring increasingly throughout Europe, diminishing their quality and preventing subsequent use of the groundwater.

Historically, the problems of water scarcity have been most acute in southern Europe and while this is generally still the case the spatial extent and severity of water stress is growing in parts of the north too. The impacts of water scarcity are likely to be exacerbated in the future, with predicted increases in the frequency and severity of droughts, driven by climate change. Droughts are distinct from water scarcity, being a natural phenomenon defined as a sustained and extensive occurrence of below-average water availability. The major challenge provided by water scarcity and droughts has been recognised in a communication from the European Commission (EC, 2007a), which estimated that at least 11 % of Europe's population and 17 % of its territory have been affected by water scarcity to date and put the cost of droughts in Europe over the past thirty years at EUR 100 billion.

Photo 1.1 © Irum Shahid/Stock.xchng

1.2 Objectives

This report provides an up-to-date assessment of water resources across Europe with the key objectives of:

- describing spatial patterns and trends in water availability and abstraction, identifying those regions subject to the greatest water stress and the detrimental impacts that ensue;
- increasing awareness of the challenges of water scarcity and drought and the need for a fundamental shift to a more demand-led and therefore sustainable approach to water resource management;
- illustrating good practice across all relevant economic sectors with respect to demand-led sustainable water resource management;
- exploring the quality of current information on water availability and water use and thereby identifying gaps in knowledge.

1.3 Outline

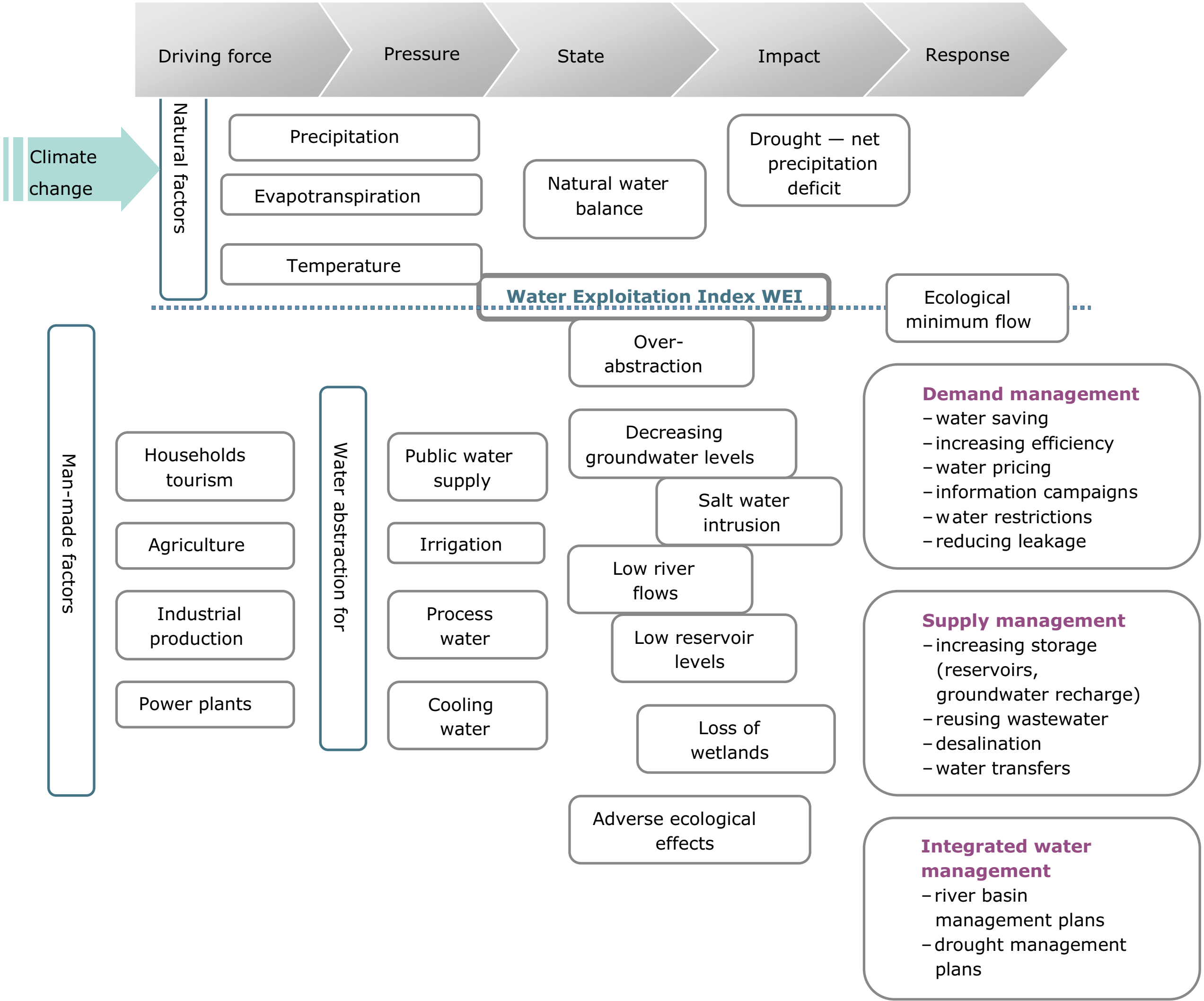
This report is based broadly upon the DPSIR (Driving force, Pressure, State, Impact and

Response) assessment framework, as illustrated in Figure 1.1. Perceived using the framework, water resources management has both 'natural' and anthropogenic driving forces. The former include spatial and temporal variation in water availability and the future impact of climate change, particularly with respect to the frequency and severity of droughts (Chapter 2). Anthropogenic driving forces are addressed first in general terms (Chapter 2) and subsequently through a detailed overview of each of the key sectors that use water: industry and energy production (Chapter 4), public water supply (Chapter 5) and agriculture (Chapter 6). Each of these sector-specific chapters reviews the key drivers of abstraction, the pressure these put on water resources and potential measures or responses that could ensure more sustainable use of water in the future.

The combined effect of abstraction and drought upon Europe's water resources is illustrated using examples of decreasing groundwater and lake levels, reduced river flows, the drying up of wetlands and the increasing occurrence of saline intrusion into aquifers (Chapter 3). Detrimental impacts upon freshwater ecosystems are also described there.

The concluding chapter (Chapter 7) highlights the need for a sustainable and integrated management of water resources in Europe in the future. Central to this are demand-led approaches that focus upon efficiency and conservation, with water pricing playing a principal role. The need to address illegal water use is also highlighted. Chapter 7 also describes recent initiatives to improve information on Europe's water resources, including the establishment of water accounting.

Figure 1.1 The DPSIR framework with respect to water resource management



Source: EEA, 2008.

2 Water availability, abstraction and supply

As a whole, Europe abstracts a relatively small proportion of its renewable freshwater resource. Nonetheless, problems of water scarcity arise in many regions due to an imbalance between abstraction and availability. This imbalance is primarily driven by a mismatch between the distribution of people across Europe and the availability of water. In certain locations this is exacerbated by excessive abstraction rates.

Explaining the current pattern and severity of water scarcity across Europe requires knowledge of the magnitude and variation of both availability and abstraction at appropriate spatial and temporal scales. In addition, predicting future changes in the availability of freshwater requires an understanding of the likely impact of climate change. This chapter outlines the availability of freshwater across Europe, using precipitation and river flow to describe the current observed variation in the resource, historical trends and likely climate-driven future trends, including those of droughts. The abstraction of water across Europe is also summarised, including the key sectors involved, their regional variation and the means of ensuring supply. Finally, a measure of the severity and spatial variation of stress on Europe's freshwater is presented as a precursor to a more detailed examination of the impacts of abstraction and supply in Chapter 3.

2.1 Water availability

2.1.1 Precipitation

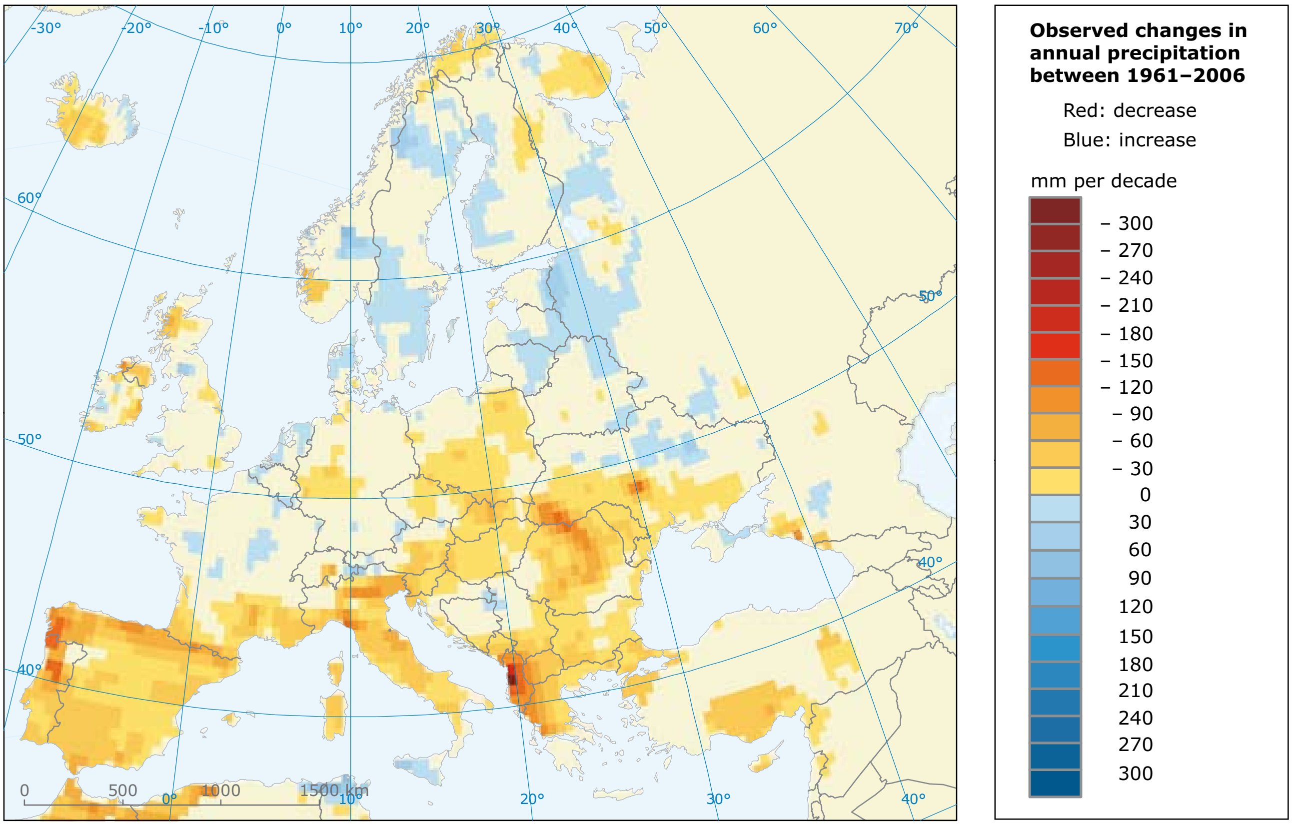
The combined influences of latitude, topography and distance to the sea result in a widely varying distribution of precipitation across Europe, ranging from less than 400 mm/year in parts of the Mediterranean region and the central plains of Europe to more than 1 000 mm/year along the Atlantic shores from Spain to Norway, the Alps and their eastern extension (JRC, 2006). Much of this precipitation is lost as evapotranspiration, however, and the remaining 'effective rainfall' is no greater than 250 mm/year across much of Europe. In some parts of southern Europe effective rainfall is lower than 50 mm/year (JRC, 2006).

Precipitation in Europe generally increased over the twentieth century, rising by 6–8 % on average between 1901 and 2005. Large geographical differences are apparent, however, notably a reduction in the Mediterranean and eastern Europe (EEA, 2008; Map 2.1). In addition, some seasonal changes have occurred, notably an increase in winter precipitation for most of western and northern Europe and a decrease in southern Europe and parts of central Europe.

Climate models predict a general future increase in precipitation in northern Europe and a decrease in southern Europe. Seasonally, a large increase in winter precipitation is predicted for mid and northern Europe, while many parts of Europe are expected to experience drier summers (EEA, 2008). Furthermore, more frequent and intense droughts are predicted across much of Europe over coming decades. This can be illustrated, for example, by the predicted number of consecutive dry days, defined as days with precipitation below 1 mm (Figure 2.1; Sillmann and Roeckner, 2008). In southern Europe, the maximum number of these days is projected to increase substantially during the 21st century whilst in central Europe prolongation of longest dry period is by one week. Thus regions in Europe that are dry now are projected to become drier still.

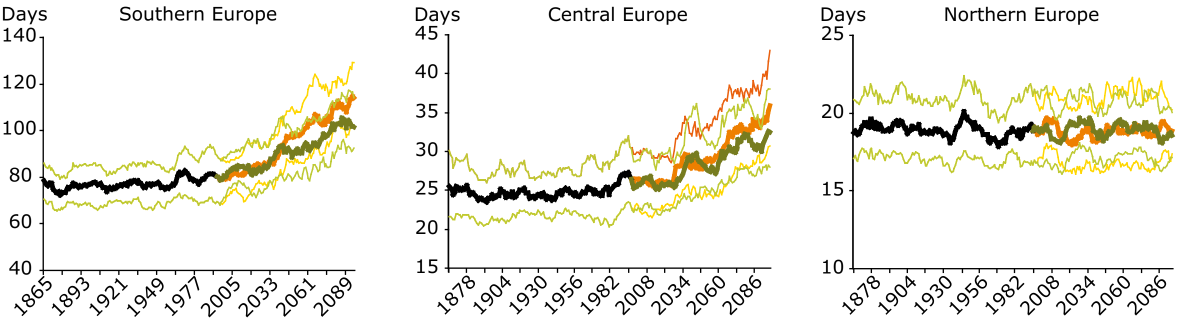
Drought is a natural phenomenon defined as sustained and extensive occurrence of below average water availability. It affects all components of the water cycle, manifesting itself in everything from low soil moisture and reduced groundwater levels, to the drying up of wetlands and reductions in river flow. Drought should not be confused with aridity, which is a long-term average feature of a dry climate. It is also distinct from water scarcity, which constitutes an imbalance between water availability and demand.

Map 2.1 Observed changes in annual precipitation 1961–2006



Source: The data come from two projects: ENSEMBLES (http://www.ensembles-eu.org) and ECA&D (http://eca.knmi.nl).

Figure 2.1 Simulated land average maximum number of consecutive dry days for different European regions (1860–2100)



Source: Sillmann and Roeckner, 2008.

2.1.2 *River flows*

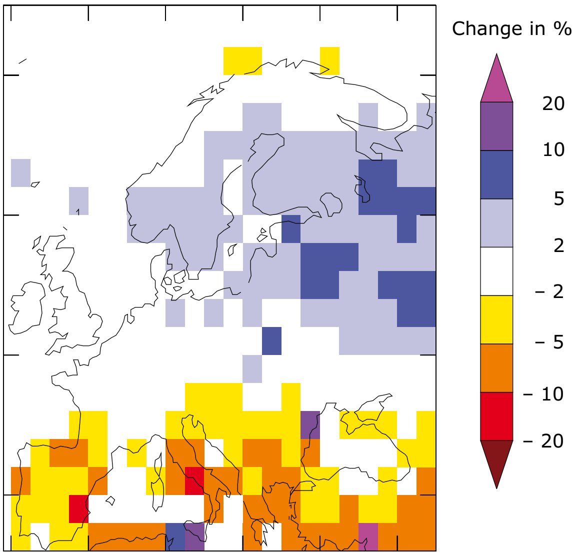
River flows are a measure of the availability of freshwater resources within a basin and very broadly correlate with the relative amount of water also stored within lakes, groundwater and wetlands. Variations in river flow are determined mainly by precipitation and temperature, as well as by catchment characteristics such as geology, soils and land cover.

Average river flow across Europe is about 450 mm/year but this varies significantly, ranging from less than 50 mm/year in areas such as southern Spain to more than 1 500 mm/year in parts of the Atlantic coast and the Alps. Seasonal variation in river flow varies throughout Europe. In the south, for example, river flow may be minimal during the summer months followed by occasional and intense rainfall events that result in dramatic but short-lived rises in river flow. This flow regime makes it very difficult to maintain a reliable supply of water from rivers without storing it in, for example, reservoirs. In west Europe there is much less variation in flow throughout the year owing to the Atlantic maritime climate. In the north and east much winter precipitation falls as snow and a large proportion of river flow thus occurs during spring snowmelt. Hydrogeological characteristics also play a role in determining the seasonality of the flow regime; rivers predominantly fed by groundwater, for example, tend to have a higher dry season flow than those dominated by surface runoff.

There is some evidence for climate induced changes in both annual river flow (Map 2.2) and the seasonality of river flow in Europe during the twentieth century. Annual flows have followed a rising trend in northern parts of Europe, with increases mainly in winter, and a decreasing trend in southern parts of Europe. Determining the role of climate change in historical alterations in river flow is not easy, however, since most river basins in Europe have been subject to large and evolving anthropogenic influences on the water balance during the twentieth century, including abstraction and flow regulation.

Annual river flow is projected to decrease in southern and south-eastern Europe and increase in northern and north-eastern Europe (Arnell, 2004; Milly *et al.*, 2005; Alcamo *et al.*, 2007; Environment Agency, 2008a). Strong changes are also projected in the seasonality of river flows, with large differences across Europe. Winter and spring river flows are projected to increase in most parts of Europe, except for the most southern and south-eastern regions. In summer and autumn, river flows are projected to decrease in most of Europe, except for northern and north-eastern regions where autumn flows are projected to increase (Dankers and Feyen, 2008). Predicted reductions in summer flow are greatest for southern and south-eastern Europe, in line with the predicted increase in the frequency and severity of drought in this region.

Map 2.2 Modelled change in annual river flow (per cent) for the period 1971–1998 relative to 1900–1970



Note: The map is based on an ensemble of 12 climate models and validated against observed river flows.

Source: Milly *et al.*, 2005.

2.1.3 *Storage*

The storage or retention of water in snow and glaciers is a key component of the hydrological cycle. Changes to these stores can fundamentally impact upon the availability of water, both seasonally and in the longer-term. For example, in snow-dominated regions, such as the Alps, Scandinavia and the Baltic, a predicted fall in winter retention as snow, earlier snowmelt and reduced summer precipitation are expected to reduce river flows in summer (Andréasson *et al.*, 2004; Jasper *et al.*, 2004; Barnett *et al.*, 2005), when demand for water is typically at its highest. The Alps, often described as the water tower of Europe, currently provide 40 % of Europe's freshwater. The Alpine region, however, has experienced temperature increases of 1.48 °C in the last hundred years —

twice the global average. Glaciers are melting, the snowline is rising and the mountain range is gradually changing the way it collects and stores water in winter and distributes it in the summer months (EEA, 2009).

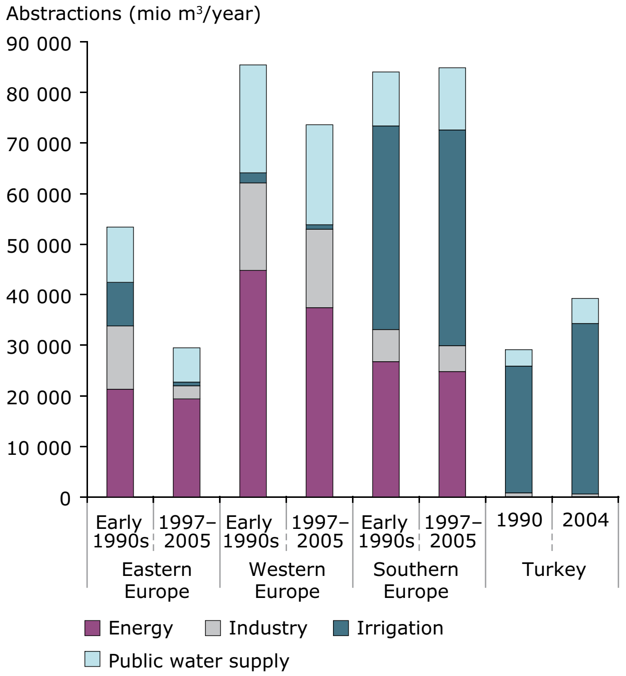
2.2 Abstraction

'Abstraction' refers to the volume of water taken from a natural or modified (e.g. reservoirs) resource over a certain period of time, typically the calendar year. It does not, however, describe how much of this volume is ultimately returned to a water body after use or how much is 'consumed' either through incorporation into a final product or by evaporation. Water consumption varies significantly between sectors. For example, water abstracted for electricity generation is nearly all returned to a water body. Contrastingly, much of that abstracted for agriculture is consumed by evapotranspiration or by being bound up in the plant.

The total abstraction of freshwater across Europe is around 288 km^3/year and represents, on average, 530 m^3 per capita/year. Overall, 44 % of the total abstracted is for energy production, 24 % for agriculture, 21 % for the public water supply and 11 % for industry, although strong regional variations are apparent (Figure 2.2). In Eastern countries, the greatest abstractor is the electricity generation sector (> 50 %), followed by public water supply (20 %). In western countries, abstraction for electricity production predominates, contributing approximately 52 % to total abstraction, followed by public water supply (29 %) and industry (18 %). In southern countries, the largest abstraction of water is for agricultural purposes, specifically irrigation, which typically accounts for about 60 % of the total abstracted, rising to 80 % in certain locations.

Sectoral trends in water abstraction are apparent over recent years (Figure 2.2). Abstraction for irrigation and industry has declined in eastern Europe since the early 1990s and increased for irrigation in Turkey. In western Europe, modest decreases in water abstracted for industry and electricity production are apparent. These various trends and the driving forces behind them are examined in more detail in the sector specific chapters of this report.

Figure 2.2 Water abstraction for irrigation, manufacturing industry, energy cooling and public water supply (million m^3/year) in the early 1990s and the period 1997–2005



Source: EEA Core Set Indicator CSI 18, based on data from Eurostat data table: Annual water abstraction by source and by sector.

2.2.1 *Sources of water*

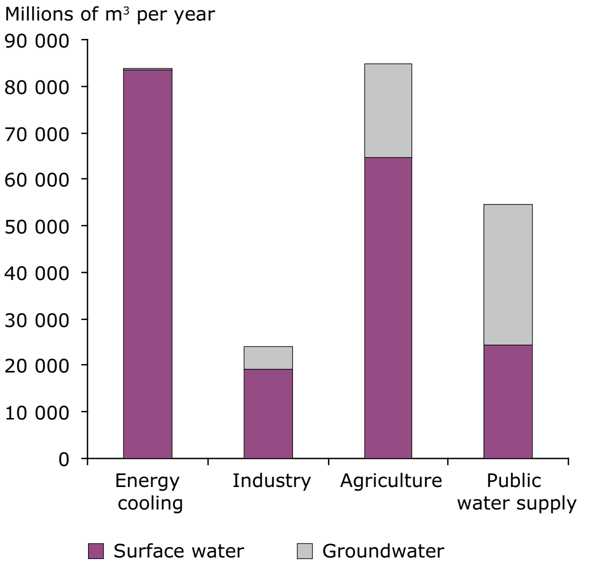
Sources of freshwater include natural water bodies, i.e. surface water (rivers and lakes) and groundwater; production by desalination; collected rainwater; and re-used wastewater. Across Europe as a whole, surface water is the predominant source of freshwater, mainly because it can be abstracted easily, in large volumes and at relatively low cost. It therefore accounts for 81 % of the total abstracted.

Virtually all abstraction for energy production and more than 75 % of that abstracted for industry and agriculture comes from surface sources (Figure 2.3). For agriculture, however, groundwater's role as a source is probably underestimated due to illegal abstraction from wells. Groundwater is the predominant source (about 55 %) for public water supply due to its generally higher quality than surface water. In addition, in some locations it provides a more reliable supply than surface water in the summer months.

2.3 Supply

All sectors abstracting water require a reliable supply that can provide sufficient water even during periods of prolonged low rainfall. As a

Figure 2.3 Sources of freshwater abstraction by sector (million m³/year)



Source: EEA, based on data from Eurostat data table: Annual water abstraction by source and by sector.

result, the storage of surface water in reservoirs is commonplace and transfers of water between river basins also occur. In addition, the artificial recharge of groundwater by river water, particularly during periods of high flow, has been a traditional means of improving supply. The production of freshwater via desalination plants is also playing an increasing role across Europe.

2.3.1 *Reservoirs*

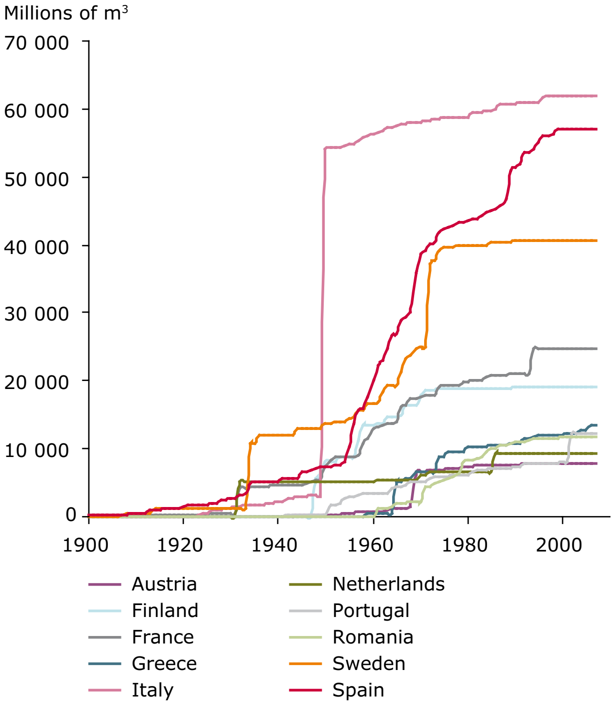
Reservoirs, created by damming rivers or modifying natural lakes, provide a means of storing and ensuring the supply of surface water. Artificial reservoirs have been constructed in Europe for hundreds of years with the oldest still in use dating back to the second century. Over the last two centuries there has been a marked increase in the height of dams and the storage capacity of reservoirs. These changes occurred to facilitate the generation of hydropower, to control flooding, and to supply water primarily for drinking, industrial production and crop irrigation.

According to the criteria of the International Commission of Large Dams (ICOLD) there are currently about 7 000 large dams in Europe (i.e. dams higher that 15 m or reservoir with a capacity greater than 3 hm³). The number of large reservoirs is highest in Spain (ca 1 200), Turkey (ca 610), Norway (ca 360) Italy (ca 570), France (ca 550), the United Kingdom (ca 500) and Sweden (ca 190). Many European countries also have numerous smaller dammed lakes.

Europe's reservoirs have a total capacity of about 1 400 km³ or 20 % of the overall available freshwater resource (EEA, 2007). Three countries with relatively limited water resources, Romania, Spain and Turkey, are able to store more than 40 % of their renewable resource. Another five countries, Bulgaria, Cyprus, Czech Republic, Sweden and Ukraine, have smaller but significant storage capacities (20–40 %).

The number and volume of reservoirs across Europe grew rapidly over the twentieth century (Figure 2.4). This rate has slowed considerably in recent years, primarily because most of the suitable river sites for damming have been used but also due to growing concerns over the environmental impacts of reservoirs.

Figure 2.4 Growth of total national reservoir volume (millions of m³) for selected EU Member States over the twentieth century



Source: EEA Eldred 2.08 (European Lakes, Dams and Reservoirs Database), 2008.

2.3.2 *Inter-basin transfers*

The options for ensuring and increasing water supply include the transfer of water from one river basin to another. Such inter-basin transfers have been used in Europe since Roman times, with the first Roman aqueduct (Aqua Appia) constructed in 312 BC to bring water to Rome from a site 16.4 km away. Remains of Roman-built aqueducts — some of them still functioning — may be found from Turkey in the east to Spain, France and the United Kingdom in the west. More modern inter-basin transfers in Europe have taken place mainly in the Mediterranean region and have often involved building hundreds of kilometres of artificial concrete channels. Nowadays, as in Cyprus during 2008, freshwater is also transported using ships to address temporary critical water shortages.

2.3.3 *Artificial water recharge*

Artificial water recharge is a process by which water, originally from a surface source, is stored in the ground. This process increases the groundwater resource and filtration within the soil and dilution with groundwater also improves the quality of the original surface water. The water used for recharge may be excess storm water, river water or treated wastewater and the technologies used include surface infiltration, injection wells, artificial ponds and percolation tanks. The selection of the system must take into consideration aspects such as topography, soil type and the quality and availability of the surface water and groundwater. Whichever method is chosen, it is essential to ensure that the pre-treatment of the surface water is sufficient to prevent soil contamination but also that the resultant groundwater is suitable for any subsequent use.

Artificial water recharge has been practiced widely in Europe since the nineteenth century and today is used to produce drinking water in Belgium, Cyprus, the Czech Republic, Denmark, Finland, Greece, the Netherlands, Poland, and Spain. In Finland, 12 % of the water produced by municipal water supplies originates from artificial groundwater, a share which is estimated to grow to 25 % by 2030 (Isomäki, 2007). In Cyprus about 10 % of drinking water needs are met using the artificial recharge of downstream aquifers by water released from dams. Additionally, both dam water and treated wastewater are used to artificially recharge aquifers that are subsequently pumped for irrigation purposes. Such use of treated wastewater in Cyprus is expected to increase significantly in coming years. Artificial recharge of coastal aquifers in Cyprus is also used to control against seawater intrusion.

2.3.4 *Desalination*

Desalination is the process of removing salts from brackish or sea water. It has become a fast growing alternative to more traditional sources of water, particularly in water-stressed regions of the world. The two technologies used by conventional desalination plants — evaporation and reverse osmosis (which involves pushing water through a semi-permeable membrane that retains dissolved salts) — both require a large amount of energy. For example, a typical seawater reverse osmosis plant requires 1.5–2.5 kWh of electricity to produce 1 m^3 of water (Service, 2006). The energy requirements of desalination plants have, however, decreased significantly in recent years and further falls may occur in the future due to the development of new techniques based on nanotechnology and novel polymers. In addition to desalination, reverse osmosis can also be used for water decontamination, purification and recycling.

Spain is the largest user of desalination technologies in the western world. Globally, it ranks fourth behind Saudi Arabia, the United Arab Emirates and Kuwait, and first in the use of desalinated water for agriculture. Its 700 plants produce some 1 600 000 m^3 of water per day or enough for 8 million people (WWF, 2007b). Other Mediterranean countries, e.g. Cyprus, Greece, Italy, Malta and Portugal, also rely increasingly on desalinated water as an additional resource for public water supply and to support holiday resorts in arid areas. Malta, for example, relies on desalination for 57 % of its water supply. In Cyprus, two permanent desalination plants with a total target capacity of 120 000 m^3/day have been constructed and a mobile desalination plant with a capacity of 20 000 m^3/day has also been installed. The Government of Cyprus is planning the installation of additional desalination plants (both mobile and permanent) in the areas of Limassol, Paphos and Vasilikos with a target capacity of approximately 130 000 m^3/day. Desalination also occurs in regions not normally regarded as arid; London's water utility Thames Water is currently investing EUR 300 million to build the region's first desalination plant (Thames Water, 2009).

2.4 Alternative supply methods

The more conventional methods of securing water supply, such as reservoirs, inter-basin transfers and desalination, all have negative environmental impacts (as described in Chapter 3 below). Continued expansion of reservoirs and water-transfer schemes, in particular, is therefore not sustainable in the longer term. As a result, alternative and potentially more sustainable means of ensuring water supply have become increasingly important in recent years. These methods include rainwater harvesting, re-use of treated wastewater and re-use of greywater (household wastewater other than that from toilets). Although none of these methods reduces water use, all have the potential to decrease abstraction from conventional sources.

Treated urban wastewater provides a dependable water supply relatively unaffected by periods of drought or low rainfall. So far, however, Europe has not invested heavily in the use of wastewater, with the current total volume re-used (964 Mm^3/year) representing only 2.4 % of treated effluent (Mediterranean EUWI Wastewater Reuse Working Group, 2007). Spain accounts for the largest proportion of this (347 Mm^3/year) with Italy using 233 Mm^3/year. In both countries treated wastewater is used primarily in agriculture (see Chapter 6) and in Europe as a whole 75 % of re-used wastewater is directed to agriculture (Mediterranean EUWI Wastewater Reuse Working Group, 2007). Additional uses include irrigation of golf courses and municipal land and, increasingly, use by industry.

Greywater (addressed in Chapter 5) is collected, stored and re-used, untreated, for flushing toilets and watering gardens. Rainwater harvesting (Chapter 5) is the process of collecting, diverting and storing rainwater from an impervious area, such as a roof, for subsequent use. Typically the water collected is used for gardening or car washing but it can support non-potable uses indoors, such as supplying washing machines and toilets.

The sectoral chapters of this report describe these alternative and potentially more sustainable means of supply in more detail, together with measures to reduce water demand and improve the efficiency of its use.

2.5 Water exploitation index

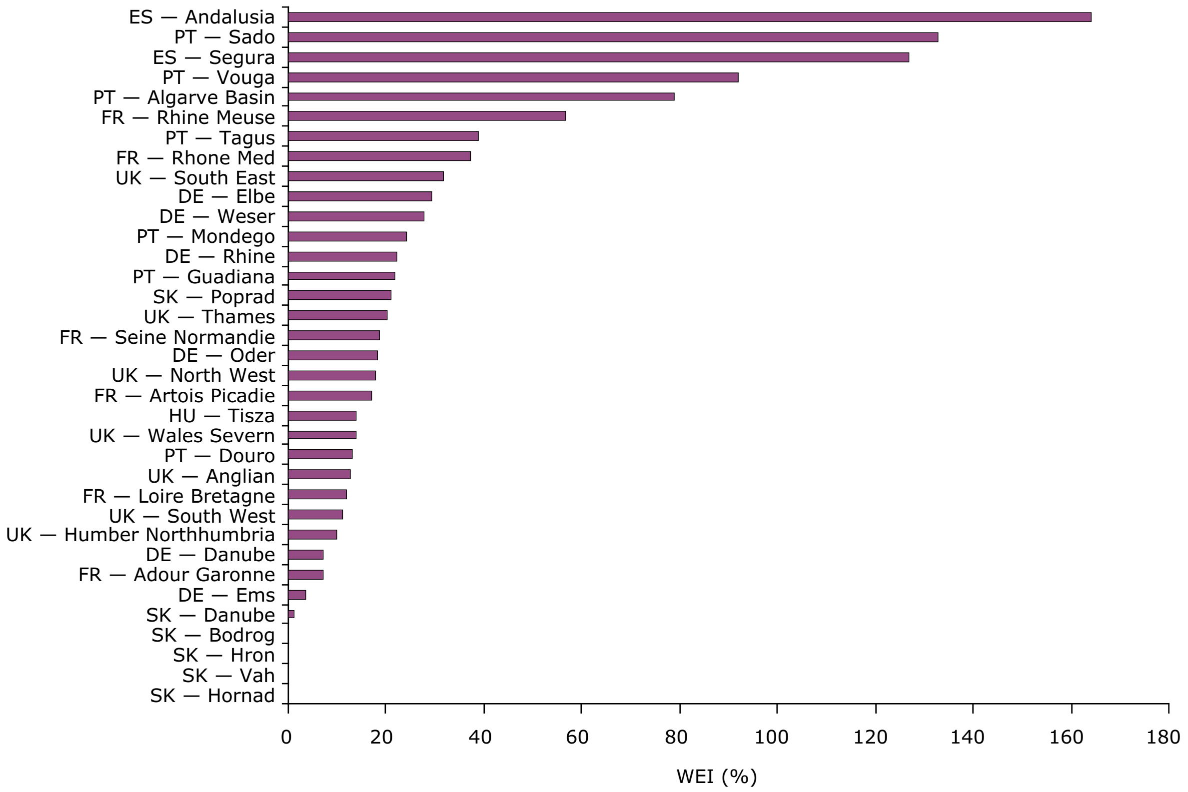
One relatively straightforward indicator of the pressure or stress on freshwater resources is the water exploitation index (WEI), which is calculated annually as the ratio of total freshwater abstraction to the total renewable resource. A WEI above 20 % implies that a water resource is under stress and values above 40 % indicate severe water stress and clearly unsustainable use of the water resource (Raskin *et al.*, 1997).

National estimates showed Cyprus (45 %) and Bulgaria (38 %) to have the highest WEI scores in Europe, with high values also apparent for Italy, Spain, the former Yugoslav Republic of Macedonia and Malta. National estimates of this sort do not, however, reflect the extent and severity of water scarcity in sub-national regions. For example, while Spain's national WEI is approximately 34 %, the southern river basins of Andalusia and Segura have extremely high WEIs of 164 % and 127 %, respectively.

In 2007, as part of the European Commission's assessment of water scarcity and drought, thirteen Member States submitted information on river basin WEIs (EC, 2007b). These data (Figure 2.5) indicate that several river basins in southern Europe have extremely high WEIs and that a number of river basins in more northerly regions have WEIs of roughly 20 %, indicating a stress on the water resource.

Although calculating the WEI at a river basin scale provides additional detail, such analysis still struggles to reflect fully the level of stress upon local water resources. This is primarily because the WEI is based on annual data and cannot, therefore, account for seasonal variations in water availability and abstraction. During the summer months in southern Europe, for example, agricultural and tourist water demands peak at a time when the natural water resource reaches a minimum. The annual average approach of the WEI is unable to capture this and cannot, therefore, fully reflect the potential threat to, for example, the freshwater ecosystem. On the other hand, the WEI can overestimate water stress because it does not account for the consumptive use of water. Where abstraction is dominated by power generation, for instance, nearly all the abstracted water is returned to the source.

Figure 2.5 WEI for selected river basins across Europe



Source: EEA based on data submitted to the European Commission, 2007.

Despite its limitations, the WEI still provides a useful indication of water scarcity and there is a broad geographical correlation between those river basins with the highest WEI and reports, from a range of sources, of diminished water resources and associated detrimental impacts, some of which are described in the next chapter.

3 Impacts of water abstraction and supply

While natural variations in the hydrological cycle, such as drought and periods of low rainfall, play a key role in determining the availability of freshwater resources, abstraction and storage can greatly exacerbate problems of water shortages.

A diminished water resource can be reflected by reduced river flows, lowered lake and groundwater levels and a drying up of wetlands. Due to the hydrological connectivity between such bodies of water, excessive abstraction from any one of them can impact upon one or more of the others. For example, rivers, lakes and wetlands can all be strongly dependent upon groundwater, especially in the summer months when it typically provides baseflow critical to the survival of surface water biota. Lack of water also harms terrestrial ecosystems, diminishing both plant and animal life.

As explained in the following sections of this chapter, water abstraction has negative impacts that extend beyond the harm to freshwater and terrestrial ecosystems. Abstraction can worsen water quality by reducing the ability to dilute pollutants while excessive abstraction from coastal aquifers can cause the intrusion of saltwater, diminishing the quality of the groundwater and preventing its subsequent use. A heavy aquifer draw down can also lead to ground subsidence and related geomorphological impacts. Additionally, a general drying out of soil surface layers can promote sealing and enhance overland flow during rainfall, thereby increasing the washing of pollutants into nearby watercourses. Unfortunately, the traditional supply side approaches to water management are also directly associated with a range of negative impacts on the aquatic environment.

3.1 Depletion of the water resource

Photo 3.1 © Stock.xpert

The effects of over-abstraction upon water resources vary considerably depending upon the volume and seasonality of the abstraction, the volume and location of returned water, the sensitivity of the ecosystem and specific local and regional conditions. Of critical importance is the timing of abstraction. Peak abstraction for both agriculture and tourism (mainly via the public water supply) typically occurs in the summer months when water availability is generally at a minimum. As a result, the potential for detrimental impacts upon, for example, freshwater ecology is maximised.

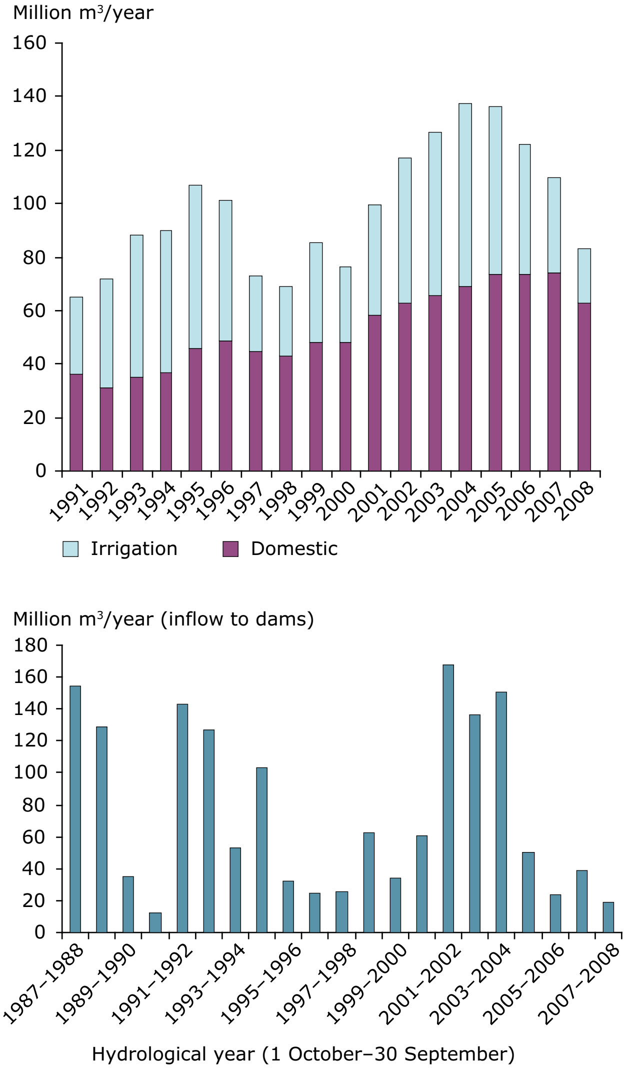
Imbalance between demand and water availability becomes most acute when abstraction occurs during prolonged dry periods or drought. Under these circumstances, a negative feedback can occur, particularly with agricultural water use, whereby the lack of rainfall drives greater abstraction in order to fulfil crop water requirements. The balance between water abstraction and availability has now reached a critical level in many areas of Europe and, as illustrated by the following examples, a combination of drought and over-abstraction by at least one economic sector are, typically, the causal factors.

3.1.1 Cyprus

The annual supply of water from the Government Water Works in Cyprus has grown steadily over the last 20 years and has exceeded 80 million m^3 each year since 2001 (Figure 3.1 upper). Fifty to seventy per cent of this figure is used for domestic purposes and the remainder for irrigation. The domestic supply includes that from desalination, with 32.6 million m^3 coming from this source in 2008. The annual available natural water resource, as reflected by the inflow to dams (Figure 3.1 lower), varies markedly from 10–40 million m^3 in dry years to 120–170 million m^3 in wet years. In wet years, therefore, Cyprus has sufficient water available to satisfy demand. In drier years, however, a large deficit can occur, despite the additional supply from desalination.

Figure 3.1 The annual supply of water from the government water works, Cyprus, to both the domestic and irrigation sectors (upper)

The annual available natural water resource, Cyprus (lower)



Source: Government of Cyprus, 2008.

In 2008, Cyprus suffered its fourth consecutive year of low rainfall and the drought situation reached a critical level in the summer months. To ease the island's crisis, water was shipped in from Greece using tankers. In addition, the Cypriot Government was forced to apply emergency measures, including the cutting of domestic supplies by 25–30 %. In one village in Limassol district, water pricing to reflect the growing scarcity was introduced, with use above a threshold level subject to sharply escalating charges (Cyprus Mail 11.10.2008). The biggest water users, particularly those with swimming pools, received bills in the thousands of euros, resulting in a drastic reduction in water use. In addition to water pricing, the Cypriot authorities have recognised the importance of alternative water sources, such as treated municipal effluents, and are increasingly exploiting them.

3.1.2 *Turkey*

The combination of drought and excessive abstraction has also had severe consequences in Turkey, with the country's second largest lake, Lake Tuz in the arid Konya basin, now having dried up completely. The lake, which in the past was visited by thousands of flamingos each summer, has begun the process of transforming into a salt basin. Although the Konya basin has experienced drought conditions since the 1980s, excessive water abstraction for irrigation has also played a critical role, with much of it drawn from illegally drilled wells (Dogdu and Sagnak, 2008). Together the lack of rainfall and excessive abstraction for agriculture has severely depleted groundwater, causing levels to decrease markedly in recent years. In addition to Lake Tuz, numerous smaller lakes and wetlands in the Konya basin, dependent upon groundwater, have also dried up.

3.1.3 *Greece*

The Vocha plain, bounded by the Korinthiakos Gulf in Southern Greece, has experienced a 65 % increase in population since the 1970s and continued growth is predicted over the coming years (Voudouris, 2006). During the summer the population increases by 25 % due to an influx of tourists and weekend visits by inhabitants of nearby Athens. Daily per capita water use is estimated to be 250 litres during summer and 200 litres in winter. Agriculture accounts for approximately 80 % of the region's water demand, with about 45 km^2 of irrigated land supporting the cultivation of citrus fruits, olives, apricots and vineyards. Irrigation occurs primarily between May and October, although some flood irrigation occurs during winter and spring.

Both the public water supply and agricultural water requirements of the area are predominantly met from groundwater, supported by around 1 500 wells and boreholes. Groundwater abstraction now exceeds recharge and the aquifer system is overexploited. Water balance estimates for 2000–2001, for example, estimate a deficit of 15 million m^3 year, reflecting a 38 % exceedance of the renewable freshwater resource. As a result, the water level has declined significantly in wells and boreholes, driving a progressive deepening of those still operating. In addition, seasonal seawater now intrudes into the aquifer (Voudouris *et al.*, 2000).

Close to the Vocha plain, the water demand of the Greater Athens region has, historically, been met through an extensive and complex water supply system that extends over an area of 4 000 km^2 and incorporates four reservoirs, 350 km^2 of main aqueducts, 15 pumping stations and more than 100 boreholes (Xenos *et al.*, 2002). Two of the reservoirs, the Mornos and Evinos, lie more than 200 km from the city. The onset of prolonged drought in the late 1980s, however, led to a substantial depletion of all surface water resources and a greater focus on the demand side of water management in Athens. This included drastic increases in the price of water, discounts in price for significant water conservation, a water saving campaign and restrictions on water use. As a result, water use at the time was reduced by one third.

Unfortunately, water demand in the Greater Athens region has continued to grow at an excessive rate, currently reaching 6 % per year. This expansion has been driven by a growth of the urban region and the movement of people from city apartment blocks to houses with gardens on the fringes of the region (Xenos *et al.*, 2002). Should this growth in demand continue, within a few years the available resource will not be sufficient to meet requirements (Koutsoyiannis *et al.*, 2001). Moreover, the potential for augmenting the system through additional supplies is extremely limited and likely to be excessively expensive, particularly given the long distances and associated pumping requirements.

3.1.4 Spain

In Spain, the water administration has identified 51 hydrogeological units as overexploited, whereby the ratio of groundwater abstraction to the renewable resource ranges between 1.0 and 1.2 (Custodio 2002). In 23 other units the ratio is in the range 0.8–1.0, whilst in a further 25 units, where the ratio is less than 0.8, significant local water-level drawdown rates or quality deterioration are reported. The decline in groundwater levels over recent decades has been particularly marked in the Segura River Basin in eastern Spain, with drawdown in the most critical areas of 20–160 m between 1980 and 2000 (Custodio, 2002).

3.2 Ecological impacts

Rivers require a sufficient amount of water, termed the 'environmental flow', in order to maintain a healthy aquatic ecosystem. While all aspects of the flow regime are important to the health of river ecosystems, low flows represent a particular risk to migratory fish that require sufficient flow to trigger upstream movement towards spawning grounds. In order to drift-feed, young salmonid fish likewise require a flow of sufficient velocity and prefer to avoid shallow water.

The concept of environmental flows applies not only to fish but the whole aquatic ecosystem, including freshwater invertebrates, vegetation and riparian bird life. Flow also strongly influences water quality, with lower flow diminishing the river's ability to dilute pollutants. The tolerance of aquatic biota to changes in river flow, velocity and depth, water quality, cover and substrate, varies from one species to another. Such information is often integrated within freshwater habitat suitability models that determine optimal flow conditions and help to quantify the impact of abstractions upon aquatic habitat.

Despite the critical importance of flow to aquatic life, abstraction of water from rivers is often excessive. As a result, rivers commonly fail to achieve and maintain environmental flows, particularly during the summer months when water availability is typically at a minimum.

Negative ecological impacts associated with low flows are often reported across Europe. In Turkey, for example, a combination of drought and excessive abstraction of water for irrigation had a severe impact, in 2000, upon the migrant fish *Chalcalburnus tarichi*, a member of the carp family that spawns in rivers feeding Lake Van in eastern Turkey (Sari *et al.*, 2003). Since then, however, research has been undertaken to identify minimum flow rates to protect the fish. Agreement has now been reached regarding a more sustainable abstraction of water, and farmer training and advisory programmes have been successfully implemented regarding irrigation techniques and the effects of over-abstraction (Sari *et al.*, 2003).

The ecological impacts of water abstraction are also evident in northern Europe. The chalk streams of southern England, for example, support a rich diversity of fish, invertebrates and plant life, including trout, salmon, the depressed river mussel, the native white-clawed crayfish and water-crowfoot. These streams are, however, vulnerable to a variety of threats, including excessive water abstraction (Environment Agency, 2004). For example, the River Piddle, a small chalk stream in Dorset, supports a valuable fishery for brown trout but is also heavily used for water abstraction. Investigations into the impacts of the largest public water supply abstraction on the brown trout population in the river have demonstrated a spatial correlation between a zone of reduced river flow and an area where juvenile trout are less abundant and good quality trout fishing is available for shorter periods (Strevens, 1999). Addressing the ecosystem flow requirements of such chalk streams is achieved by developing catchment abstraction management strategies (CAMS) in England and Wales (Environment Agency, 2008c). These provide a framework for assessing resource availability and a licensing strategy that aids sustainable management of water resources on a catchment scale.

Lakes and reservoirs also require a minimum amount of water for healthy ecosystem function; excessive abstraction can impact negatively on the open water ecosystem and its marginal zones. Lake Dojran/Dojirani, located in the Former Yugoslav Republic of Macedonia and Greece, has experienced a marked drop in water volume in recent decades, falling from 262 million m^3 in the 1950s to 65 million m^3 in 2002. This decrease is attributable to both prolonged periods of drought and excessive abstraction for agriculture, with an estimated 12 million m^3 used for irrigation annually (Manley *et al.*, 2008). The diminished water resource, together with worsening water quality, have resulted in reduced numbers of all fish species in the lake and caused a large scale exodus of some species of birds.

Excessive abstraction can also affect terrestrial ecosystems, leading to the drying out of woodland, forests, heathland, dunes and fens, making them less suitable for characteristic plant and animal life. In the Doñana National Park in south-west Spain, for example, abstraction of water for tourism and agriculture in the surrounding area has contributed to a loss of wetland grasses and heathland, promoting an invasion of scrub vegetation (Muñoz-Reinoso, 2001). The drying of peatland has particular implications for climate change, since the aeration and oxidation that occurs lead to a loss of accumulated organic matter and change peat soils from sinks into sources of carbon. In the Guadiana catchment in Spain, the drying out of peatland through excessive groundwater abstraction and rainfall scarcity has at times resulted in its spontaneous combustion and almost all of the peat is now burnt (Fornes *et al.*, 2000).

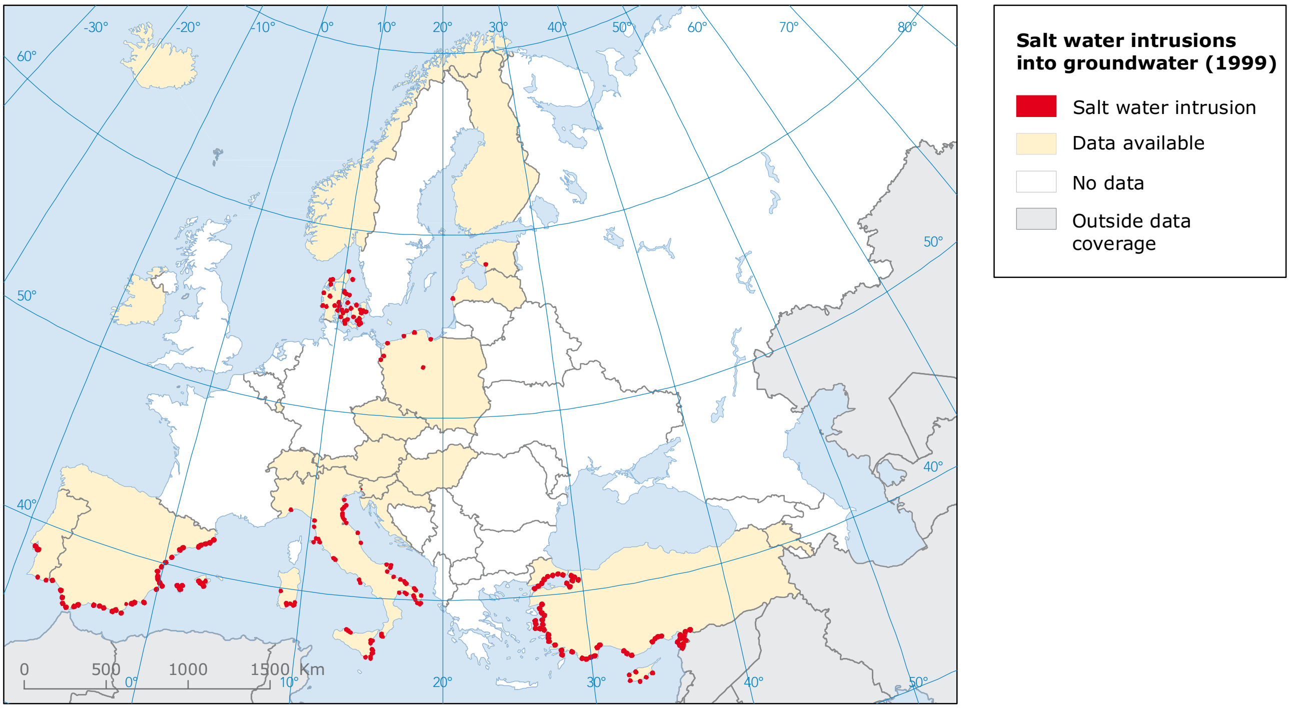
3.3 Saline intrusion

Excessive groundwater abstraction from a coastal aquifer causes the freshwater level to lower and seawater to flow into the aquifer — a process known as saline intrusion. This diminishes the quality of the aquifer and prevents the subsequent use of the groundwater because conventional treatment methods do not remove the salt. Furthermore, the normally lengthy residence time of groundwater means that the saline contamination may remain for decades. Typically saline intrusion of groundwater results in the demand for freshwater being met by other sources, including desalination of coastal water.

Large areas of the Mediterranean coastline have been affected by saline intrusion driven by abstraction of water for agriculture and public water supply, with demand for the latter being markedly increased by tourism. Across Greece, for example, it is estimated that the total surface area of aquifers impacted by seawater intrusion is about 1 500 km^2 (Daskalaki and Voudouris, 2007). While the problem is most acute in Mediterranean coastal regions, saline intrusion also occurs in northern Europe (Map 3.1), with the general situation as shown for 1999 having progressively worsened since.

The Argolid Plain in eastern Peloponnesus in Greece has undergone a rapid expansion of irrigated agriculture since the 1950s. Groundwater abstraction to support the irrigation of oranges, horticultural crops and olives has been excessive and led to the intrusion of sea water into aquifers. This phenomenon was first recorded in the early 1960s, when groundwater, pumped from certain wells, showed an increase in the concentration of chloride. Signs of chloride toxicity, such as leaf burns and defoliation, particularly in citrus trees, were also observed (Poulovassilis and Giannoulopoulos, 1999). The decline in the groundwater resource has resulted in the drying up of boreholes and the abandonment of those with excessively high salinity.

Map 3.1 Saltwater intrusions into groundwater in Europe (1999)



Source: EEA, 2007.

New boreholes have been drilled further from the coast and both existing and new boreholes have been dug to increasing depths.

In Cyprus, 12 of the 19 groundwater bodies (63 %) have been intruded to some extent or are at risk of sea water intrusion (MAP, 2007). Drought and increasing water demand, combined with reduced recharge caused by the construction of dams on those streams feeding the coastal aquifers, have together caused the decline of groundwater levels and the associated seawater intrusion. The situation has been exacerbated by a pricing policy that charged for water abstracted from reservoirs but not from groundwater. In addition to the saline intrusion, natural marsh areas have been depleted.

3.4 Adverse impacts of supply-side measures

Traditional supply-side approaches to water management are associated with various negative impacts upon the aquatic environment. In particular, reservoirs, inter-basin transfers and desalination each cause specific problems by modifying water quantity, water quality, or both.

3.4.1 Reservoirs

Reservoirs cause a number of environmental problems both during the building phase that may take decades and following completion. As the water level in the reservoir rises following the closing of the dam, major changes often take place in the area to be inundated. Farmland, terrestrial and riparian habitats can be lost, settlements flooded and the groundwater table elevated.

Once the reservoir has been established, the environmental problems can be divided in two groups. The first type renders the reservoir unsuitable for its purpose and includes, for example, algae and toxic substances in reservoirs used for drinking water. The second comprises problems that induce deterioration of the river system, especially downstream of the reservoir. Since dams interrupt the natural continuity of a river, fragmentation of the river ecosystem occurs, often with marked ecological consequences. In particular, the dam may obstruct access to spawning sites for migratory fish, the problem being especially acute for fish such as salmon, trout, eel and sturgeon. Much of the sediment carried into reservoirs becomes trapped and settles to the bottom. Not only does this sedimentation reduce the lifespan of the reservoir but water released by the dam is also depleted in sediment and organic material that would otherwise contribute to the fertility of the floodplains and estuaries downstream. This depletion also leads to a reduction in the quality and extent of the downstream aquatic habitat.

3.4.2 Water transfers

Analysis by WWF has identified several drawbacks associated with the large scale transfer of water between river basins (WWF, 2007a). These include the loss of water via evaporation and seepage from channels during transport (as much as 50 %) and, at the donor's end, reduced river flow, an increased concentration of pollutants due to a lower dilution capacity, changes to erosion and sedimentation patterns and changes to the freshwater ecosystem. In addition, such transfers have the potential to introduce alien species to the receiving basin, fragment the landscape and impact adversely upon terrestrial habitats, particularly during the building phase.

3.4.3 Desalination

Although desalination reduces the need for freshwater abstraction it is associated with environmental problems. As noted in Section 2.3.4 above, desalination uses considerable amounts of energy to evaporate water or force it though membranes. In this respect the use of solar power can play an increasingly important role in the future. In addition to the energy requirements, huge amounts of liquid or solid waste (brine) are released in the desalination process.

To minimise environmental damage at the intake, desalination plants should not be located in sensitive marine and coastal environments and screening of the intake should be undertaken. Whether disposal of brine has a large scale effect on sea salinity and currents is still an unresolved issue but local effects of brine effluents are well-documented. Being heavier than normal seawater, brine effluents tend to spread along the sea floor, where they threaten bottom-dwelling organisms sensitive to salinity, such as high biological value meadows of the sea-grass *Posidonia oceanica* (WWF, 2007b). One solution to the brine problem is to reduce it to a solid or minimum possible form and use it as an input in the chemicals industry or deposit it in former mines.

4 Water abstraction for industry and energy production

Water is used by manufacturing industries in a number of different ways: for cleaning, heating and cooling; to generate steam; to transport dissolved substances or particulates; as a raw material; as a solvent; and as a constituent part of the product itself (e.g. in the beverage industry). Overall, manufacturing industry uses about 11 % of the total freshwater abstracted across Europe, with about half used for processing and the remainder for cooling. Manufacturing industry is supplied both from the public water supply system and via 'self' abstraction processes; the more water-intensive industries generally undertake their own abstraction, with the principal source being surface water.

Water abstracted for energy production accounts for about 44 % of the total freshwater abstracted across Europe, although in Germany, France and Poland this figure exceeds 50 %. Very little water abstracted for energy production is consumed, with the majority ultimately discharged back to a receiving water body at a higher temperature. Thermal, fossil and nuclear power plants all require large amounts of water for the generation of electricity and heating. The water abstracted is used primarily for cooling, although some is used as 'boiler feed' and 'process' water. Most of the water requirements of power plants are met from surface water and extracted almost exclusively using their own abstraction plants. Cooling water is generally treated before use in order to avoid corrosion and calcification and also to fight the growth of bacteria and algae in the cooling system.

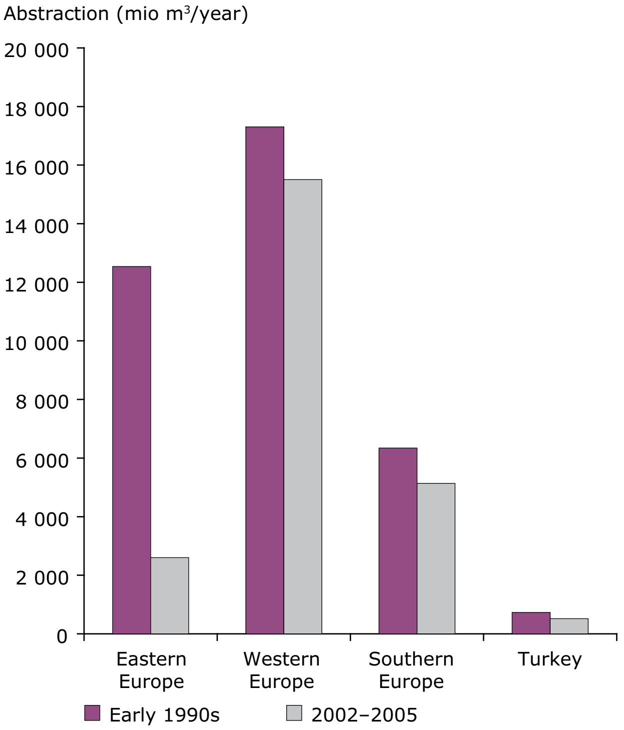
4.1 Water use by manufacturing industry

4.1.1 *Current status and recent trends*

Following major growth between 1950 and 1980, water abstraction by manufacturing industry in Europe stabilised during the 1980s. Since the mid-1990s the trend has reversed, with abstraction falling despite continued expansion of industrial output (Figure 4.1). This reduction has been greatest in eastern Europe (approximately 79 %) and is associated primarily with the significant decline in industry during the transition process (Dworak *et al*., 2007). Elsewhere, the reductions can generally be attributed to the decline of very water-intensive heavy industry (e.g. mining and steel manufacture); attempts in some sectors to reduce water costs, including those associated with discharging wastewater; and the introduction of more water-efficient technology (Dworak *et al*., 2007).

Currently, just two countries, Germany and France, account for more than 40 % of European water abstraction by manufacturing industry. England and Wales, Sweden, the Netherlands, Austria, Finland,

Figure 4.1 Water abstraction for manufacturing industry (millions of m^3/year) in the early 1990s and the period 2002–2005



Source: EEA Core Set Indicator CSI 18, based on data from Eurostat data table: Annual water abstraction by source and by sector.

Norway and Romania are also relatively large contributors to the European total (Figure 4.2).

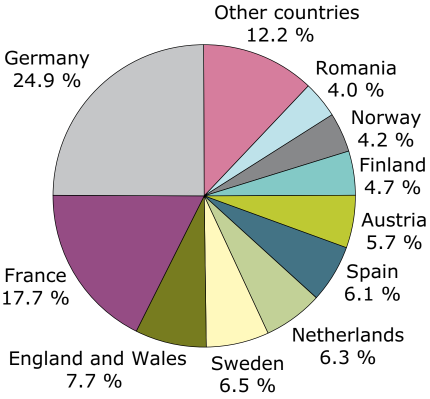
The various manufacturing sectors account for differing proportions of total industrial water use in Europe. Data reported to Eurostat indicate that the chemicals and petroleum refinement industries are responsible for approximately half of all water use by manufacturing industry, while the basic metals, paper and food processing industries account for much of the remainder.

4.1.2 *Reducing water use in the manufacturing sector*

Manufacturing industry can reduce its water use by recycling and reusing water, changing production processes and using more efficient technology, including measures to reduce leakage (Dworak *et al.*, 2007). Growth in the recycling of water within industrial plants has been driven, in part, by the development of on-site treatment, with advanced techniques such as reverse osmosis playing an important role. Relatively simple techniques for on-site treatment of wastewater have also been proven to be effective. In Swansea, the United Kingdom, for example, a drive-through hand car wash and valeting centre has installed a closed loop water recycling system, using reed beds to treat wastewater (Environment Agency, 2007a). The reed-bed system has resulted in a 60 % decline in the use of the public water supply and a similar decrease in the discharge of wastewater. Likewise, a manufacturer of stone and hard landscaping products in Lancashire, the United Kingdom, has used a settlement technique to separate heavy particles from wastewater and subsequently recycle the extracted material. The remaining water is fed back into the production process and, together with the harvesting of rainwater, has led to a 95 % reduction in metered water use (Environment Agency, 2007a).

Photo 4.1 © Stock.xpert

Figure 4.2 Country share of total water abstraction for manufacturing industry



Source: EEA, based on latest available data (2000–2005) from Eurostat data table: Annual water abstraction by source and by sector.

Sector-specific declines in industrial water use are increasingly reported. The European Chemicals Industry (CEFIC, 2007), for example, has estimated that water abstracted by chemicals industries across Europe, used primarily for cooling, has reduced by 8 % between 2003 and 2006. Reductions have also occurred in the paper industry, with water abstraction for paper and cardboard production in Austria, for example, falling by more than half between 1990 and 2007 (Austropapier, 2007).

In Denmark, significant improvements in water use efficiency across many sectors have been ongoing for some years; the amount of water used to produce a litre of beer, slaughter a pig, manufacture a kilogram of paper and produce a cubic metre of glass wool, all decreased significantly during the 1990s. A number of examples of sector-specific water savings, including their financial benefits, are described by Dworak *et al.* (2007).

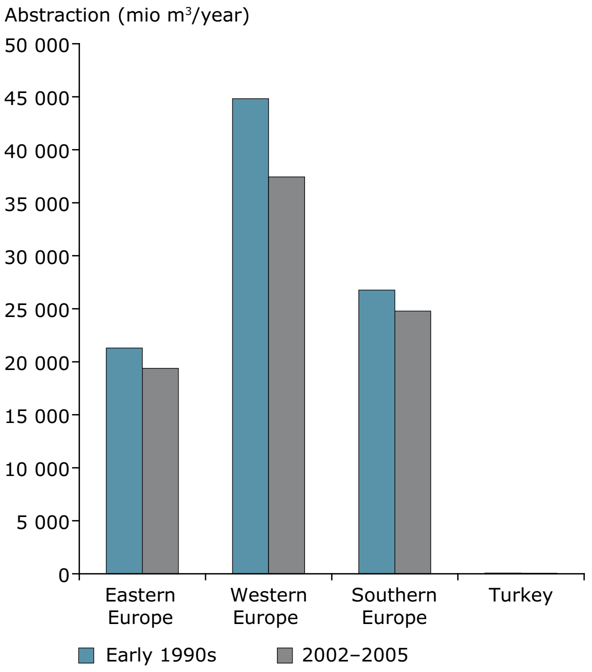
4.2 Water use for energy production

The use of cooling water has decreased by about 10 % across Europe as a whole over the last 10 to 15 years (Figure 4.3). In some countries, for example Germany and France, this decrease has exceeded 20 %, while in others, such as the Netherlands, England and Wales and Poland, abstraction has remained broadly constant. In the future, decreased precipitation and higher temperatures are expected to have an adverse impact, at times, on the electricity generation sector where rivers provide cooling water. This is because power stations have to be shut down when the temperature of intake water or river levels fall below certain thresholds (EEA, 2008). Electricity production has already been significantly reduced in various locations in Europe during very warm summers (Lehner *et al.*, 2005).

Traditionally, cooling has been undertaken using 'once-through' systems whereby water is returned to a receiving water body, at higher temperature, immediately after use. This approach requires a large volume of abstracted water per unit of electricity produced, although only about 1 % of the amount abstracted is actually consumed (Electric Power Research Institute, 2002).

More modern 'cooling tower' or 'recirculation' systems require less abstracted water than once-through systems. Their progressive introduction explains, in part, the general reduction in abstraction for cooling purposes across Europe over the last 10 to 15 years. Following the cooling process, recirculation systems remove heat from the cooling water through contact with air in a cooling tower, a process that results in a consumptive loss of water via evaporation. The remaining water can then be re-circulated and re-used for cooling purposes. Unlike the once-through approach, recirculation systems do not discharge heated water and therefore avoid the potential for adverse impacts on thermally sensitive aquatic ecosystems.

Figure 4.3 Water abstraction for energy cooling (million m³/year) in the early 1990s and 2002–2005



Source: EEA Core Set Indicator CSI 18, based on data from Eurostat data table: Annual water abstraction by source and by sector.

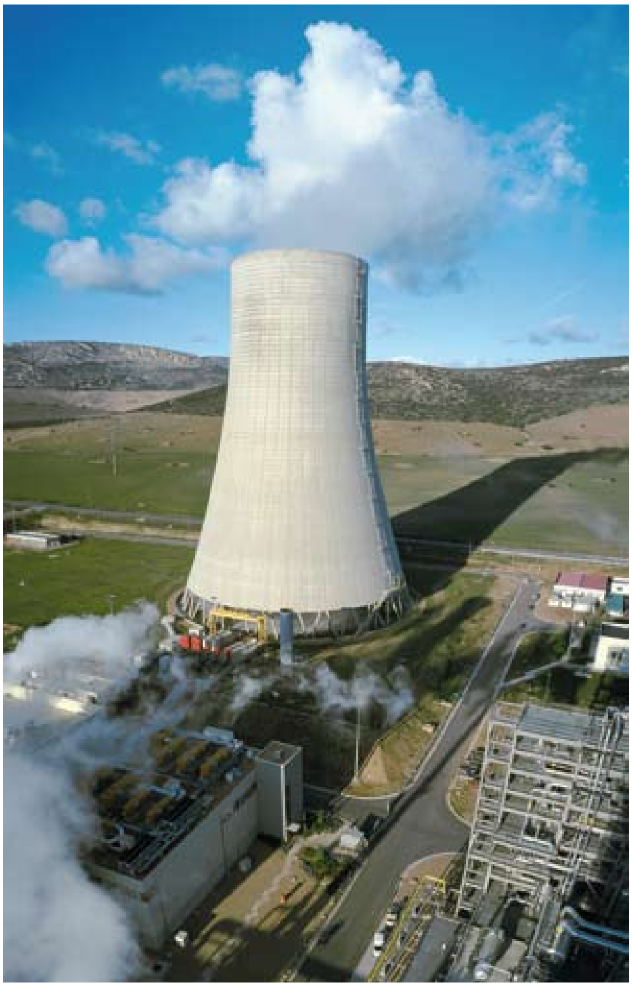


Photo 4.2 © Stock.xchng

The ongoing replacement of older once-through systems with more advanced cooling technology, including recirculation, dry and hybrid systems is likely to drive further reductions in abstraction for energy production in the future. In addition, there is potential for a greater use of alternative water sources for energy production purposes, particularly as cooling (and boiler feed) water does not typically need to be high quality. Such alternative sources can be less impacted by drought than higher quality freshwater sources.

5 Public water supply

Approximately 21 % of water abstraction across Europe supplies public water systems, although significant variation exists between countries. Public water not only includes the supply to households but also to small businesses, hotels, offices, hospitals, schools and some industries.

Only 20 % of water used by the various sectors receiving a public water supply is actually consumed, with the remaining 80 % being returned to the environment primarily as treated wastewater (EEA, 2003). Urbanisation can, however, lead to a depletion of groundwater resources, particularly because sealed surfaces typically direct rainfall to sewer networks preventing it from infiltrating soil; groundwater is often a key source of public water supply; and discharges from urban wastewater treatment plants are generally returned to rivers rather than augmenting groundwater stocks.

The key drivers influencing public water demand are population and household size, income, consumer behaviour and tourist activities. Technological developments, including the degree to which leakage in the public water supply system is addressed, also play an important role.

5.1 Forces driving use of the public water supply

5.1.1 Population and household size

The total population of the EU-27 countries has increased from just above 400 million in 1960 to 497 million in 2007 (Eurostat, 2008a), driving an increase in the domestic use of water over this period. Continued migration is projected to gradually increase the EU-27 population to 521 million by 2035, with a gradual decline predicted thereafter, resulting in a population of 506 million in 2060 (Eurostat, 2008b).

While population size clearly impacts upon domestic use of water, the size of households, in terms of the number of occupants, is also a key driving force. Water use related to, for example, car washing, gardening and laundry is tied more closely to the household than the individual. As a result, an economy of scale exists whereby larger households use less water per capita than smaller households, as illustrated by data from London (Greater London Authority, 2007; Figure 5.1). Smaller households also contribute to a reduction in the effectiveness of water saving measures.

While Europe's population has increased over recent decades, the number of households has grown at a faster rate due to a general decrease in household size, triggered by demographic shifts such as an increase in the number of people living alone. In 2005, the average household size in EU-25 was 2.4 people per household (Eurostat, 2008c) with the highest national average recorded in Cyprus (3.0 people per household) and the lowest in Denmark (2.0 people per household).

Figure 5.1 Effect of household size on water use (litres per person per day)

Source: Greater London Authority, 2007.

5.1.2 *Tourism*

Tourism can markedly increase 'public water' use, particularly during the peak summer holiday months and especially in southern European coastal regions already subject to considerable water stress. Not only do tourists use water for food, drink and personal hygiene purposes, leisure facilities such as swimming pools, water parks and golf courses can significantly increase water use. Typically, tourists use more water than locals per capita. For example, the Organisation for Economic Co-operation and Development (OECD) reports that per capita water use by tourists in deluxe hotels in Greece averages 450 litres/day — several times higher than average use by local Greek residents (OECD, 2000). Non-tourist water use in the home generally ranges between 100 and 200 litres/per person/day across Europe.

In the Mediterranean region, international tourist numbers have risen from 58 million in 1970 to more than 228 million in 2002, with France, Spain and Italy combined welcoming about 75 % of the current influx (UNEP, 2005). Up to 80 % of tourist stays in the region are concentrated in the period May to September when water availability is at a minimum and water stress peaks. Although predictions of future tourism are uncertain, it is estimated that growth in France, Italy and Spain will continue at a rate of about 2.0–2.5 % per annum. Similar rates are reported for Cyprus and Malta, although a more rapid future growth in tourism (approximately 5 %) is predicted for Turkey (UNEP, 2005).

In the Júcar river basin in eastern Spain the regional population of about 4.36 million is effectively increased by about 1.4 million inhabitants each year due to the influx of tourists (CHJ, 2004). Ninety five per cent of the influx occurs in the Valencian Autonomous Community, particularly in coastal districts, although in recent years a growth of tourism has also occurred inland. Across the Júcar river basin the number of hotel rooms exceeds 98 000 with a very strong seasonal pattern in occupancy; in some areas the ratio of the maximum monthly occupancy to the minimum monthly occupancy exceeds 7:1. In addition, nearly 1 million dwellings are not permanently occupied, many of them second homes used only for holiday periods. In 2002, the Júcar had 19 golf courses with an average water use of between 6 500 and 10 000 m^3/ha/year. Turnover from each golf course is estimated at EUR 1.5–9 million per year, with an average of 150 employees at each. There are plans to develop a further 55 golf courses in the Júcar basin.

While the presence of a green, well-watered golf course can appear incongruous in arid areas of the Mediterranean, its use of water is no greater than that of a comparable area of irrigated corn and it yields a better financial return (UNEP, 2005). When the employment created by golf courses is also accounted for, the driving forces for their continued development throughout the Mediterranean region become apparent. A potential solution to limiting the impact of golf courses upon the water resource is the re-use of wastewater for irrigation, a practice already adopted at some golf courses within southern Europe. In the Sperone Resort, Corsica, for example, effluent is subject to lagooning and tertiary treatment by sand filtration before being used to irrigate the neighbouring golf course with a maximum application of 280 m^3/day (Mediterranean EUWI Wastewater Reuse Working Group, 2007). While other such examples exist, it is clear that there is the potential for greater use of wastewater to irrigate golf courses across Europe.

5.1.3 *Income*

Income is an important driver of public water use and as GDP increases, the proportion of households connected to public supplies increases. Higher household income is also linked to greater water use and ownership and increased capacity of water appliances (e.g. showers, toilets, water heaters, dishwashers, washing machines, sprinklers and swimming pools).

A sigmoid (S-shaped) curve has been used to describe the relationship between per capita domestic water use and national income (Flörke and Alcamo, 2004), whereby at low income levels water use initially accelerates sharply with the development of economies and lifestyles. Upon reaching a threshold where the average household is fully provided with dishwashers, washing machines and other appliances, water use then stabilises or decreases with any further increase in GDP. Decreases can often be explained by a greater water saving awareness and the use of more water efficient technologies.

Regardless of its precise nature, the positive relationship between public water use and GDP/income/wealth at lower earnings levels indicates that future increases in household usage are likely in certain areas of Europe. In particular, per capita GDP in southern and eastern countries is currently lower than in the north and west and continued economic growth is likely to result in an increase in public water use. A study of urban residential water use in the Athens metropolitan area, for example, predicts that an anticipated 3 % increase in GDP will lead to a future increase in water use of 2.5 % per annum, with an overall increase of 25 % over the period 2000–2010 (Bithas and Stoforos, 2006).

As Europeans become wealthier they buy more water use appliances. In 1970, for example, 65 % of UK households had washing machines but by 2002 this figure had increased to more than 90 %. Similar trends have been observed in other western European countries. In Denmark, for instance, ownership of both washing machines and dishwashers has grown since 1990 (Statistics Denmark, 2008a; Figure 5.2) although the household washing machine market appears now to be nearly saturated. Fewer households in western Europe own a dishwasher than a washing machine but the figure continues to grow. It should be noted, however, that this growth may not impact significantly upon household water use, since modern dishwashers are typically equally or even more water efficient than the washing of dishes by hand.

Appliance ownership data is not currently readily available for the new Member States but it is believed that rates are currently relatively low and likely to rise in the future. Higher income can also result in increased use and possession of luxury household water appliances such as power showers, jacuzzis and swimming pools. Power showers have a water use rate of about 15 litres/minute, relative to the 10 litres/minute that regular showers use.

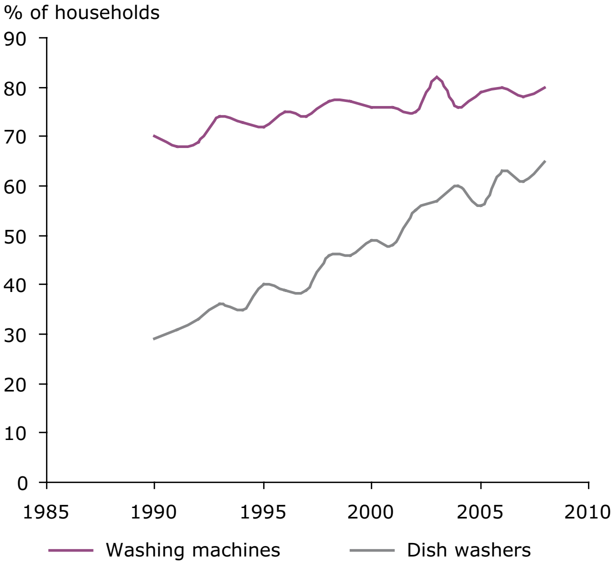
5.1.4 *Technological developments*

Recent innovations that have improved the efficiency of water appliances have been important drivers for reducing water use, promoting water savings without requiring a change in consumer behaviour or, necessarily, an awareness of water issues. Of particular note have been the technological improvements to large domestic appliances such as washing machines and dishwashers, which have led to large reductions in water usage. A number of other household devices can, however, also be adapted or updated to attain significant gains in water efficiency.

5.1.5 *Leakage*

Considerable 'loss' of water can occur in public distribution and supply networks prior to it reaching domestic premises. In some European countries there has been a focus in recent years upon reducing such loss and recent declines in leakage are apparent. In Denmark, for example, loss in recent years has reduced to 6–7 % from more than 10 % in 1996 (Statistics Denmark, 2008b). In other parts of Europe, however, water loss remains considerable.

Figure 5.2 Percentage of Danish households with washing machines and dishwashers



Source: Statistics Denmark, 2008.

In Croatia, for example, loss rates increased markedly in the late 1990s but have since stabilised at close to 40 % of the total water supply (CROSTAT, 2008).

5.1.6 *Socio-cultural influence and individual behaviour*

Changes in lifestyle, such as longer and more frequent baths and showers, more frequent use of washing machines and the desire for a green lawn during summer, can have a marked effect on household water use. Such changes may be specific to particular age groups. Older generations, for example, generally make only minor changes to the less intensive water use behaviour they grew up with, whereas younger generations are typically used to a more water-intensive lifestyle.

One behavioural change with adverse environmental impacts has been the marked rise in the consumption of bottled mineral water in Europe over recent years. Current annual consumption is in excess of 80 litres per capita, having typically increased by at least 15 % in most countries in the period 2002–2007 alone (Beverage Marketing Corporation, 2008). A large proportion of mineral water bottles are made from plastic and are therefore derived from a non-renewable resource, i.e. oil. In addition, the manufacturing process also uses water and releases carbon dioxide. The Earth Policy

Institute estimates that 2.7 million tons of plastic are used to bottle water globally each year, with an estimated 25 % of all bottled water being exported across national boundaries. Bottled water requires considerable energy to transport, thereby releasing further greenhouse gases in the process. In contrast, the transport of water from a treatment works to household taps is relatively environmentally benign (EPI, 2007).

5.2 Current and recent public water use

The driving forces identified above impact in different ways on Europe's regions and, as a result, the trends in water supply abstraction also vary. Combined total supply across the eastern countries of Bulgaria, Czech Republic, Hungary, Poland, Romania, the Slovak Republic and Slovenia declined by approximately 37 % between 1990 and the period 2002–2005 (Figure 5.3). This decline is attributed to the introduction of metering and higher water prices in the 1990s, although recent economic growth in eastern Europe is predicted to reverse the overall downward trend in the future. A similar but less marked reduction in supply is apparent for western Europe over recent years, driven by the implementation of water saving measures including leakage reduction and metering. The growth in supply within southern Europe has been driven, in part, by increasing demand from tourism. In Turkey, abstraction for public water supply has increased rapidly since the early 1990s, reflecting population growth and a rise in tourism.

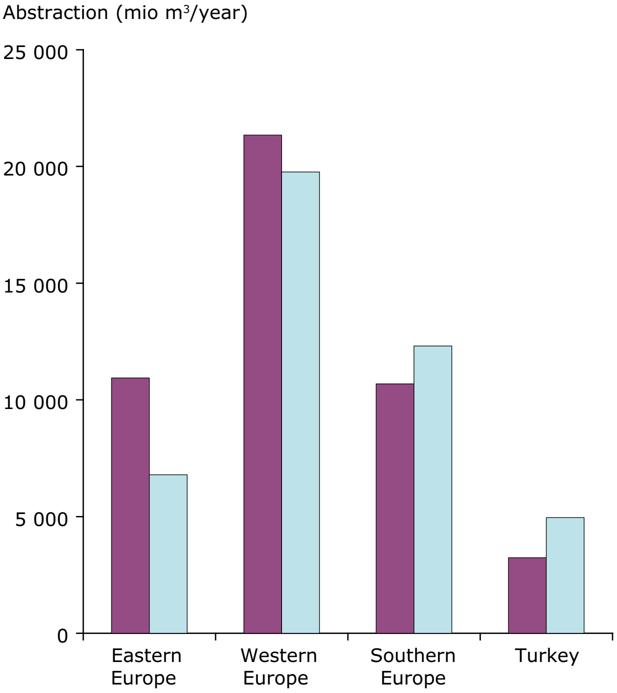
National average per capita public water supply varies widely between European countries, ranging between 50 and 150 m^3 per capita annually, reflecting the net effect of a number of drivers that can vary considerably both spatially and temporally. Household use typically accounts for 60–80 % of the public water supply across Europe with personal hygiene and toilet flushing accounting for about 60 % of this proportion.

5.3 Influence of climate change

Climate change may have an influence upon future household water demand. The limited research undertaken to date generally identifies a relatively small effect, leading to a modest increase in water demand. Downing *et al.* (2003), for example, estimate that UK household water use will increase by about 1 % by 2025 and by less than 5 % by 2050, under predictions of longer and hotter summers. Similarly, Keirle and Hayes (2007) project a 1–2 % increase in UK domestic water use by 2020 due to climate change. A clear separation is likely to exist between components that are sensitive to climate change (showering, gardening, lawn sprinkling, golf course, swimming pools and aqua parks) from those that are non-sensitive such as dish and clothes washing (EEA, 2008).

Household water use during spells of unusually hot weather also provides some indication of the effect of climate change. For example, peak water use increased as much as four-fold relative to the norm during the summer of 2003 in some Swiss kantons (BUWAL, 2004). Such strong short-term changes in water use do not, however, give a clear indication of the longer-term response (Feenstra *et al.*, 1998). While future changes in household water use due to climate change may not be marked, increases are most likely during the summer months when the general water resource is at a minimum and the adverse environmental impacts of abstraction are at their peak. In this respect, small increases in domestic use will only serve to exacerbate such impacts.

Figure 5.3 Water abstraction for public water supply (million m³/year) in the early 1990s and the period 2001–2005



Source: EEA Core Set Indicator CSI 18, based on data from Eurostat data table: Annual water abstraction by source and by sector.

5.4 Sustainable use of the public water supply

A number of measures exist that may potentially reduce the use of publicly supplied water. These can be broadly grouped into the categories of water saving devices; greywater re-use; rainwater harvesting and the efficient use of water in gardens and parks; leakage reduction; behavioural change through raising awareness; water pricing; and metering. Since treating, pumping and heating water consumes significant amounts of energy, using less publicly supplied water also reduces energy consumption.

5.4.1 Water saving devices

Modern large electric appliances such as washing machines and dishwashers have greatly improved their water use efficiency over recent decades. For example, whereas in 1970 washing a 5 kg cotton load typically required 200 litres of water, by 2004 this figure had fallen to 49 litres (Stamminger *et al.*, 2005). The water efficiency of numerous other household appliances including toilets, urinals, taps, showers and general plumbing has also improved in recent years. Considerable scope exists, however, for a greater uptake and use of such modern appliances across much of Europe.

Toilet flushing accounts for about 25–30 % of total domestic water use and as such, considerable overall water savings can be achieved by reducing flush volumes. The amount of water used for a single toilet flush has dropped considerably in some countries in recent decades, particularly as dual flush and low flush (less than 6 litres per flush) toilets have come onto European markets. In some cases, regulation has helped drive a change; under UK building standards, for example, the maximum cistern volume allowed has fallen from over 12 litres in the 1950s to just over 4 litres today.

Cistern replacement devices (e.g. 'hippos') are a simple and cheap means of reducing flush volumes, typically by about 1 litres per flush. They are particularly used in older toilets with large cistern volumes. Water can also be conserved with a delayed action inlet valve, which prevents the cistern refilling during the flush. Without such a valve, the water released is greater than the cistern's capacity — by 17 % according to one study cited in a UK Environment Agency report (Environment Agency, 2007b).

Both waterless and vacuum toilets are relatively recent technologies. The most common form of waterless toilets compost the waste, which must usually be removed manually. Composting toilets are best suited to public buildings in remote sites without a water supply. Vacuum toilets use a powerful vacuum to pull waste through the toilet, together with about 1L of water to rinse the bowl. Currently, however, vacuum toilets are typically not cost effective or practical in private homes.

Many older urinal installations do not have controls and so flush continuously, wasting significant volumes of water in public and commercial buildings. A number of flush control devices are now available, however, and provide significant water savings. These are typically timer-based or else detect the presence of people using infra-red sensors.

Water use by showers can be reduced considerably by aerating the water flow, which helps to simulate the feel of a power shower but without requiring high volumes of water. Such aeration can also be applied to water flowing through taps. Thermostatic mixing valves in both showers and taps maintain selected temperatures and have been shown to result in considerable savings of both water and energy. Taps with infra-red sensors provide water only when an object is detected beneath them, resulting in water savings of 70 % or more. Water savings can also be realised by replacing old and leaky plumbing.

5.4.2 Re-use of greywater

Greywater refers to all household wastewater other than that from toilets, i.e. wastewater from baths, showers, washbasins and the kitchen. In the most simple re-use systems greywater is stored and subsequently used, untreated, for flushing toilets and watering gardens (other than edible plants). Greywater from baths, showers and washbasins is generally preferred to that from kitchen sinks and dishwashers since it is less contaminated. The use of greywater for watering gardens and flushing toilets has been successfully implemented in Cyprus, reducing per capita water use by up to 40 %. In 2007, government subsidies covered 75 % of the cost of the system (EC, 2007a).

The microbial quality of greywater raises public health concerns, particularly when it has been stored for some time (Dixon *et al.*, 2000). Immediate use of greywater is therefore preferred, although approaches also exist to minimise the contamination of stored water. These include using electronically controlled dump valves to empty storage tanks after a certain period of inactivity and using chemical disinfectants such as chlorine to inhibit biological activity and microbial growth (Environment Agency, 2007b). More sophisticated treatment options are available but are typically prohibitively expensive for individual homes and consume significant amounts of energy. While the reuse of greywater for non-potable purposes inside the home is possible (e.g. in the initial cycle of washing machines) health concerns have generally limited this practice.

5.4.3 *Rainwater harvesting and water efficient gardening*

Rainwater flowing from a roof or driveway can be transferred via guttering or piping to a receiving container and subsequently used for activities such as gardening and car washing. Such rainwater harvesting not only reduces household use of treated public water supplies but can also make a small contribution to lessening the severity of storm discharges. The practice, typically, has little or no detrimental environmental impact. Where rainwater is harvested from metal roofs, however, any subsequent use needs to account for potentially high heavy metal concentrations in the collected rainwater.

Rainwater can also be used for non-potable purposes inside the home. For example, the Millennium Green housing development project in the United Kingdom uses rainwater not only for gardens but also for washing machines and toilet flushing (Environment Agency, 2008b). Compared to a simple garden water butt, household rainwater systems are sophisticated and their installation can be complex. Provided that it is correctly collected and stored, rainwater can be used for toilets, washing machines and gardens without further treatment.

As well as harvesting rainwater, other measures can limit the amount of water used in gardens, parks and green spaces. Adding compost, manure or bark helps soil retain moisture, while watering early in the morning or evening will reduce water loss through evapotranspiration, particularly in summer. Choosing plants that are tolerant of water scarcity, including drought resistant species, reduces the amount of watering required.

5.4.4 *Leakage reduction*

Leakage in public supply networks can be significant. Preventative maintenance and network renewal are key to minimising this loss. Modern and in some cases emerging technologies can detect leaks, significantly reducing the time taken to discover and locate a leakage. They include sensors that use the noise generated by a leak to locate it, ground radar that can identify disturbed ground or cavities around a pipe, tracer gas and devices that use radio signals to detect the presence of flowing water.

Photo 5.1 © Craig Jewell/Stock.xchng

5.4.5 *Raising awareness*

In recent years there has been a marked increase in the amount of information provided to both domestic and business water consumers, generally leading to reduced water use. Such awareness-raising campaigns encompass a number of different approaches, including websites, education programmes in schools, local authority leaflets, advertising stands at live events and the use of general media outlets (i.e. television, radio and newspapers). Typically, the larger the geographical reach of the campaign, the simpler its content.

A successful campaign to raise public, local authority and business awareness with respect to sustainable water use was undertaken in Alcobendas, a satellite town on the outskirts of Madrid with 90 000 inhabitants. The town has undergone a rapid urban and industrial development in recent years, raising pressure on the local water resource. The campaign was initiated by WWF-Spain/ADENA in collaboration with the LIFE programme of the EC (WWF/Adena, 2001). It was promoted by the Alcobendas Town Council, the community of Madrid and the Tagus River Basin Authority. The project aimed to provide the technical, legislative and educational means and market mechanisms to achieve its goals. Fundamental to those were cross-sectional awareness-raising and educational activities including:

- training professionals, such as builders, plumbers and sales people, about water saving devices;
- creating awards for the best water saving house project (for professionals) and best water saving education;
- workshops on rational use of water and a CD-ROM for 'self-auditing' on water use for industry, shops and service providers;
- disseminating water saving information through seminars, leaflets and invitations to join projects;
- using media such as radio, television and newspaper to present information on water saving.

The potential annual water savings in Alcobendas have been estimated at more than 100 million litres per year (WWF/Adena, 2001).

Eco-labelling is playing an increasingly important role in helping consumers make informed choices about the water (and energy) efficiency of the appliances they plan to buy. The EU's eco-label establishes criteria based on each stage of a product's life cycle. For example, for washing machines to achieve an eco-label, their water use must not exceed 15 litres per kg of clothes washed in a 60 °C cycle. In addition, clear instructions must be provided regarding water and energy conservation.

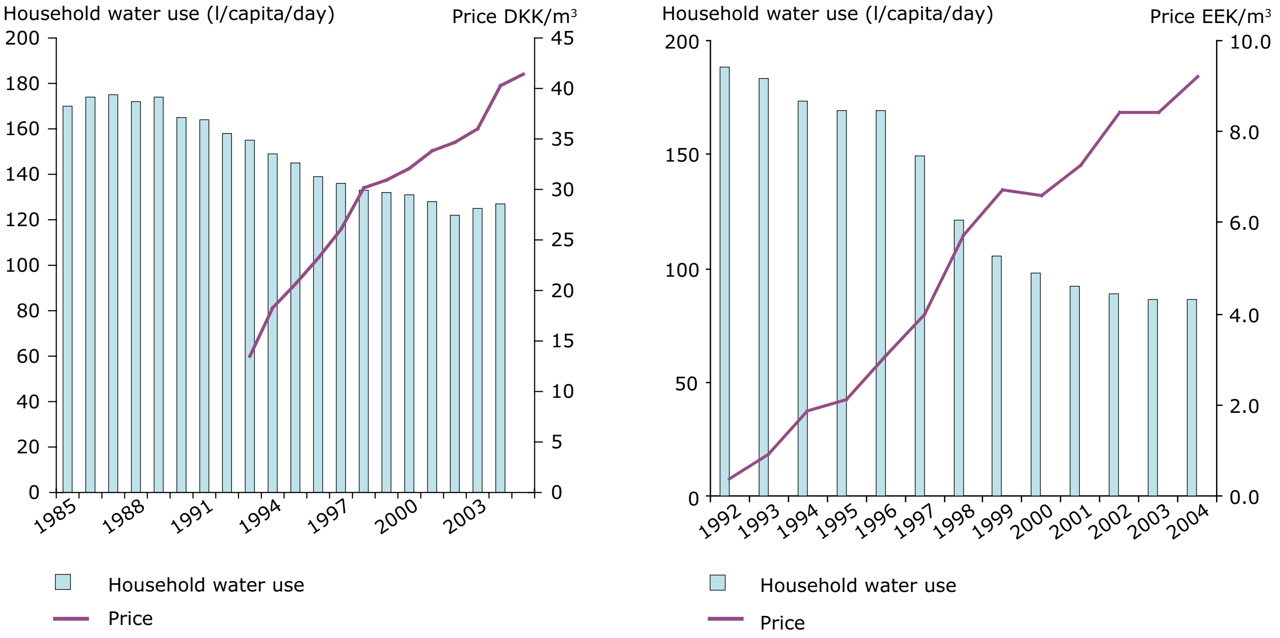
In addition to eco-labelling, the concept of eco-certification has been growing steadily within the tourism industry, particularly in Europe, where most of the schemes worldwide are located (Hamele, 2002). The Malta Tourism Authority, for example, has established an eco-certification scheme to promote water conservation in hotels based on a detailed audit system (Malta Tourism Authority, 2008). To qualify for the label, hotels have to install rainwater harvesting systems, fit showers and taps with water saving devices and monitor swimming pool water use. The reuse of treated wastewater effluent is recommended but not required. As of 2008, 13 hotels on the island (mostly 4- and 5-star hotels) were certified.

5.4.6 Water pricing and metering

As set out in the Water Framework Directive, water pricing can be a key mechanism to achieving sustainable public use of water. While most European countries are progressing towards water pricing for public supply, quantifying the effect of pricing upon use is complex due to significant variation between countries, a general lack of reliable and comparable data, cross subsidies and a masking by other water demand measures. Nevertheless, some data are available showing that water pricing has a clear impact upon public water use. In Denmark and Estonia, for example, a steady rise in the price of water since the early 1990s has resulted in a significant decline in household water use (Figure 5.4).

Fundamental to the success of water pricing is its link to the volume of water consumed, since this underpins the incentive for efficient use of water (EC, 2000). With respect to the public water supply, meters are used in homes and business premises to quantify the volume used. Metering leads to reduced water use; in England and Wales, for example, people living in metered properties use, on average, 13 % less water than those in unmetered homes (Environment Agency, 2008a). The use of meters is growing steadily throughout Europe, particularly in single-family houses, although uptake in apartments is currently low due, in part, to technical challenges. A further important issue with respect to domestic water pricing is the ability to pay, since it is generally recognised that no one should have to compromise personal hygiene and health in order to pay their water bill.

Figure 5.4 Water pricing and household water use in Denmark, 1990–2005 (left) and Estonia, 1992–2004 (right)



Source: DEPA, 2004, updated by EEA.

Source: Estonian Environment Information Centre, 2006.

6 Agricultural water use

Agriculture is a significant user of water in Europe, accounting for around 24 % of total water use. This share varies markedly, however, and can reach up to 80 % in parts of southern Europe, where irrigation of crops accounts for virtually all agricultural water use. In many regions within southern Europe, crop irrigation has been practised for centuries and is the basis of economic and social activity. Indeed, the importance of irrigation in some southern locations is such that in its absence great economic hardship would occur with the potential for land abandonment.

In northern Member States, agriculture's contribution to total water use varies from almost zero in a few countries, to over 30 % in others (IEEP, 2000). While water for irrigation is important, a significant proportion of water use in northern countries goes to livestock consumption (drinking) and cleaning livestock housing and yard assembly areas. Across the United Kingdom, for example, the irrigation and livestock components each contribute around 50 % of the estimated 300 million m^3 of water abstracted for agriculture each year (Defra, 2006). Generally, the use of water for livestock in the north occurs in areas with sufficient rainfall, where water stress is rare. As a consequence, this chapter focuses on water use for crop irrigation, particularly in southern Europe where it predominates and its adverse impacts are most marked.

In arid and semi-arid areas of the EU, including much of southern France, Greece, Italy Portugal, Cyprus and Spain, irrigation allows for crop production where water would otherwise be a limiting factor. In more humid and temperate areas, irrigation provides a way of regulating the seasonal availability of water to match agricultural needs, thereby reducing the risks to crops during periods of low rainfall or drought.

While enhancing the yield and quality of crops, irrigation can and does lead to a range of negative environmental impacts, including water scarcity. In addition, significant inputs of fertilisers and pesticides are typically applied to irrigated land to enhance production. Such chemical inputs can be greater than those associated with more traditional rain-fed cropping. Adverse impacts upon water quality are therefore common.

Photo 6.1 © Griszka Niewiadomski/Stock.xchng

The detrimental effects of excessive agricultural water use are exacerbated by its relatively high consumptive use. Although some irrigation water is 'returned' to groundwater via percolation, consumption through plant growth and evapotranspiration is typically significant and approximately 70 % of water abstracted does not return to a water body (Molle and Berkoff, 2007).

6.1 Historical driving forces of irrigated agriculture

6.1.1 *Increased productivity*

Irrigated agricultural land comprises less than one-fifth of the total cropped area globally but produces about two-fifths of the world's food (Doll and Siebert, 2002) — a statistic that clearly illustrates the increased productivity that irrigation affords. In Italy and Spain, for example, irrigated agriculture contributes more than 50 % to total agricultural production and more than 60 % to the total value of agricultural products (OECD, 2006). The area irrigated, however, encompasses only 21 % and 14 % of total agricultural land in Italy and Spain respectively. Similar statistics are reported at a regional scale; in the Castilla-La Mancha region of Spain, for example, the irrigated area represents about 11 % of the region's agricultural land but provides more than 40 % of its total agricultural production (Álvarez and Matamala, 2004). The enhanced crop yield obtained through irrigation has also been directly quantified through experimental studies. For example, Ferreira and Goncalves (2007) demonstrated that, relative to rain-fed conditions, full irrigation increased the yield of potatoes by up to 360 % in north-east Portugal.

6.1.2 Trade patterns and subsidies

Although recent commitments under the World Trade Organization are driving a gradual reduction of border protection (EEA, 2006b) the influence of markets and competition upon agriculture in the EU has historically been buffered by subsidies to farmers. These subsidies have helped to ensure that while most Member States operate charging systems for water abstraction by means of permits, licences or more general user costs, agriculture does not have to bear the true cost of its water use. In the EU as a whole, especially where large collective irrigation networks are managed by public bodies, the price of water to farmers rarely reflects its full resource and environmental cost, and hence does not act as an incentive to reduce over-abstraction.

In addition to national funding mechanisms, some irrigated crops have historically received significant support under the EU Common Agricultural Policy (CAP). These subsidies buffer the impact of global markets and competition, and have led to increased water use and a shift of traditional rain-fed crops to irrigated cultivation. In Spain, for example, olive production has traditionally been rain-fed but is now the main water consumer in the Guadalquivir region in Andalusia (WWF, 2005); nearly 300 000 ha of land devoted to olive production are now irrigated in the Guadalquivir river basin.

CAP subsidies have also been used to support water-intensive crops such as cotton and rice that are often grown using inefficient irrigation techniques. In Greece, for example, a significant proportion of cotton is grown using flood irrigation, which requires 20 000 litres of flood water to produce a kilogram of harvested crop due to high levels of surface runoff and evaporation. Drip irrigation of cotton can require 7 000 litres per kilogram of crop, although that is still seven times higher than the

Photo 6.2 Irrigated olives grown in an arid landscape in Crete © Pavel St'astny

volume of water needed for the production of a kilogram of wheat (WWF, 2006a).

While linking subsidies to production has contributed to the growth of irrigated agriculture, recent reforms of the CAP are leading to a decoupling. In addition, the reforms have strengthened the incentives to farm in an environmentally sensitive way through the adoption of agri-environmental schemes. Such schemes encompass measures related to the water resource, with the potential for a more sustainable use of water by agriculture in the future.

6.2 Future driving forces of irrigated agriculture

6.2.1 Climate change

Future increases in atmospheric carbon dioxide levels and temperature are expected to promote a lengthening of the crop growing season, resulting in increased crop yields and a general northward shift of crops in Europe. Such changes have already been observed over recent decades, with the flowering of winter wheat occurring 2–3 weeks earlier now compared to 30 years ago (Genovese 2004). The degree to which these potential future increases in crop yield are realised will, however, be strongly dependent upon the availability of water.

Annual average water availability is likely to increase generally in northern Europe. Availability in the summer months, when crop water demand peaks, may decrease, however, in some areas. In southern Europe, increased temperatures and decreased precipitation will result in a general decrease in water availability, increasingly exacerbated by an increase in the frequency and severity of droughts. In southern locations and certain areas of the north, therefore, the requirement for irrigation water is likely to rise in the future. Without appropriate management the competition for water between agriculture and other sectors is likely to increase, with a progressive worsening of water scarcity. In some southern locations, lack of water in the future may limit agriculture, causing the growing season to contract.

6.2.2 Biofuel crops and irrigation

The European Union and its Member States are committed to increasing the use of renewable energy sources, including biomass, with an EU target of a 10 % share of biofuels in transport by 2020. This will markedly increase future demand for energy crops and thus total agricultural output. Associated changes in land use and practice will have significant implications for agricultural water use depending on the crop type. If the demand for biomass from energy crops is met using standard arable crops then agricultural water demand is likely to increase, perhaps necessitating greater use of irrigation.

The introduction of new energy crops has the potential to change water use but whether the outcome is an increase or a decrease will depend on the type and management of both the introduced and replaced crop. In areas of water scarcity, any introduction of new energy crops should not lead to an increase in water use and should be used as an opportunity to reduce agricultural water demand. In this respect, certain less water demanding (e.g. switchgrass) or drought tolerant energy crops (e.g. cynara and jatropha) are clearly preferable to current first generation energy crops (EEA, 2006a; JRC/EEA, 2006).

6.3 Irrigation across Europe

The supply of water in an irrigation system can depend upon pressure or, more traditionally, gravity (without pressure). Pressure systems include sprinklers and drip irrigation systems, while gravity systems include flood irrigation of whole fields and furrow irrigation using shallow channels or ditches to carry water to the crop. Pressure systems are generally more efficient in transporting water to crops than traditional gravity systems. Although the traditional gravity approach is still apparent in Europe, particularly in the south, it is steadily being replaced.

Irrigation water can be sourced from groundwater using wells or boreholes, on-farm surface water from ponds and rivers, and off-farm surface water sources using a water distribution infrastructure connected to, for example, storage reservoirs. The continual expansion of all these sources has helped drive the growth in irrigated agriculture across Europe. The illegal abstraction of water for agricultural purposes is commonplace in certain areas, however, particularly from groundwater sources (Llamas and Garrido, 2007; WWF, 2006a; WWF, 2006b). Illegal water use may involve drilling an unlicensed well or exceeding a consented abstractable volume from wells that are licensed. In addition, it can occur from surface waters using transportable pumping devices.

Irrigation can be 'permanent', implying that it is practised throughout the year; 'support', meaning that it is undertaken over short periods during the dry and/or peak growing season; or 'temporary', meaning that it is practised only occasionally in those years when there is a particular water shortage (IEEP, 2000). In general, temporary and support irrigation are more predominantly found in northern Europe, with permanent irrigation more prevalent in the south.

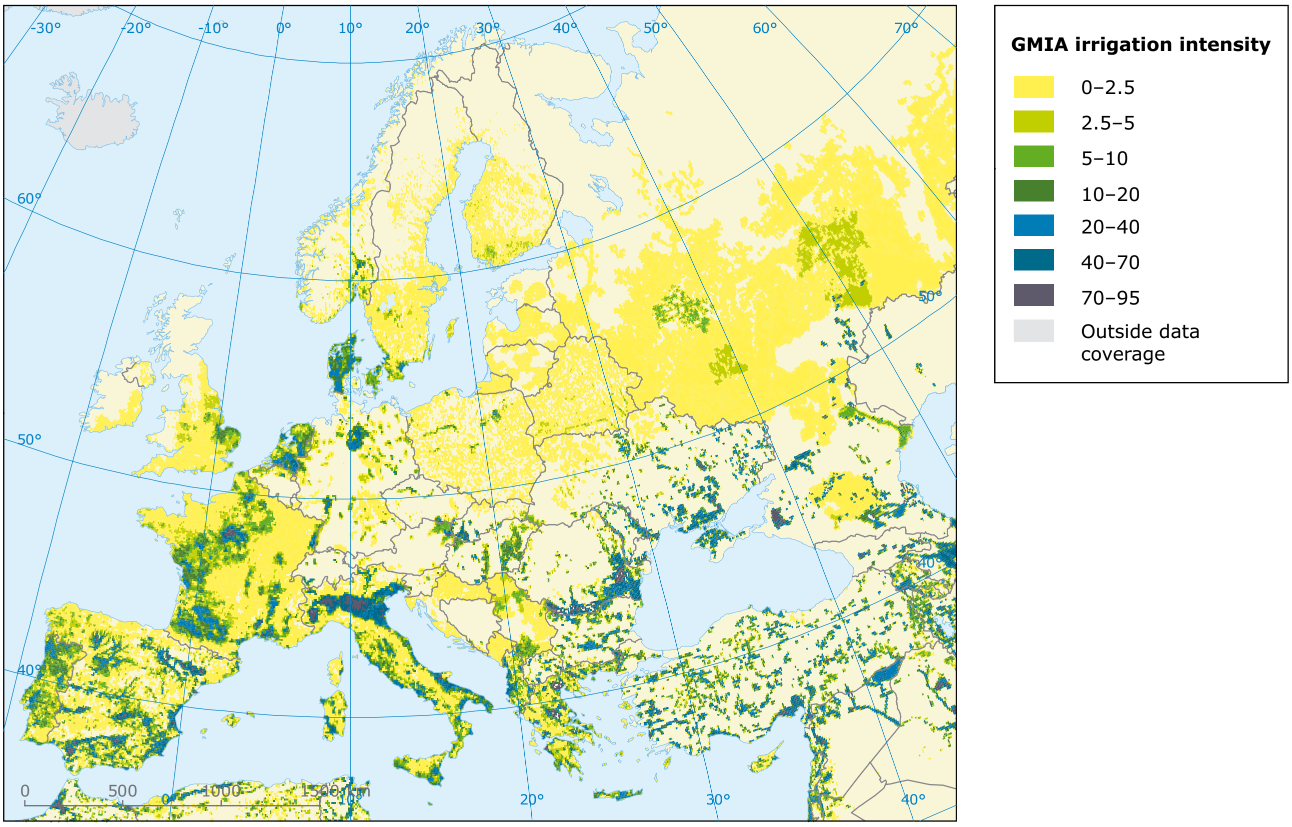
Different crops are subject to irrigation of varying intensity and fall into four main categories (IEEP, 2000):

- extensive crops characteristic of arid regions that are generally permanent and of lower value;
- semi-intensive crops irrigated on a seasonal basis or most of the cropping period, e.g. cereals, oilseed and maize;
- intensive crops that are generally high value and where irrigation is critical to maintaining yields and quality, e.g. root crops, industrial crops, open air and glasshouse horticultural crops;
- saturated crops, e.g. rice, that require the flooding of fields.

6.3.1 Irrigated area

Using a variety of sources, including land use maps, remote sensing images and reported statistics, Siebert *et al.* (2007) have derived a global data set of area equipped for irrigation at a spatial resolution of 5'. The resulting map for Europe (Map 6.1) illustrates the spatial extent and intensity of agricultural land equipped for irrigation and shows that it is broadly, although not exclusively, concentrated in Southern Europe. The intensity is highest in Southern Romania, Northern Italy (the Po plain), Spain and certain areas in Greece and Turkey. Localised areas with a high proportion of land equipped for irrigation are also apparent further to the north, for example, in the East Anglia region of the United Kingdom. It should be noted, however, that information on 'area equipped for irrigation' does not provide any indication on how often or how much water is used. Parts of northern Europe, for example, can have large areas intensively equipped for irrigation where irrigation is practised only a few times in the driest summers.

Map 6.1 Irrigation intensity across Europe, as illustrated by the percentage of area equipped for irrigation, by 5' cell, derived from the Global Map of Irrigated Areas



Source: GMIA; Siebert *et al.*, 2007.

The spatial pattern illustrated in Map 6.1 is also broadly reflected in national data from Eurostat's Farm Structure Survey (FSS), which quantifies the 'area equipped for irrigation'. This information, summarised for selected countries in Figure 6.1, confirms that the southern Member States have the greatest absolute area equipped for irrigation (in 2005), with Italy (3.97 million hectares), Spain (3.77 million hectares), France (2.71 million hectares), Greece (1.59 million hectares), Romania (0.81 million hectares) and Portugal (0.62 million hectares) the six largest. Combined, these six countries contribute almost 84 % of the total irrigated area across EU-27.

Italy (from 1995 onwards), Spain, France and Greece all exhibit a broadly increasing trend in area equipped for irrigation between 1990 and 2005. This growth has been rapid for Spain and France, although both now show a small recent decline between 2003 and 2005. In Portugal a general decline in equipped area is apparent between 1990 and 2005. Overall, the area under irrigation in the northern Mediterranean countries is expected to remain broadly constant in coming years (Blue Plan, 2005), although agricultural development policies in the southern and eastern Mediterranean countries (e.g. Algeria, Morocco, Syria and Turkey) include plans to extend the area of irrigated agriculture (Blue Plan, 2005). In this respect it is worth noting that in countries such as Turkey, agriculture plays a much greater role in the national economy than elsewhere and that the high agricultural water use is to some degree compensated for by a relatively low use by industry.

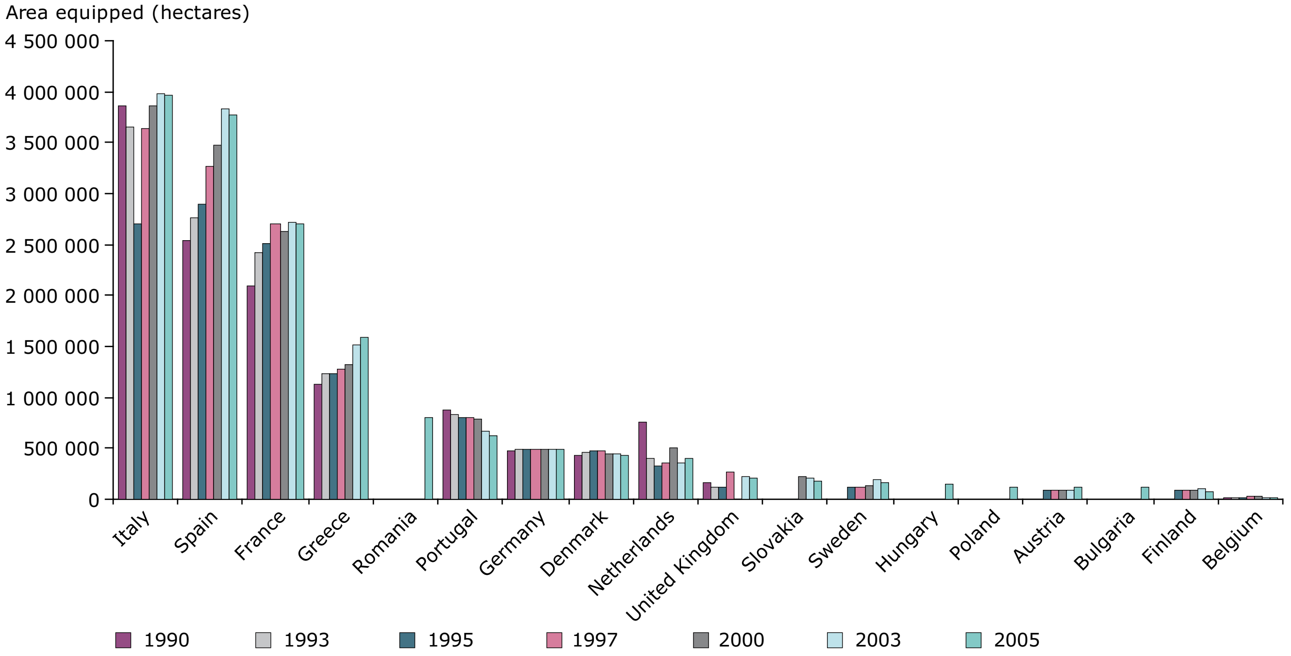
6.3.2 *National-scale abstraction*

'Irrigated area' or 'area equipped for irrigation' are useful indicators but only represent a rough surrogate for actual water use. An alternative and more direct measure is provided by data on the volume of annual water abstraction (m^3/year) for agriculture, reported at a national scale by Member countries as part of a joint OECD–Eurostat questionnaire. The OECD–Eurostat data confirms abstraction volumes are much higher in southern Europe than the other regions (Figure 6.2), with abstraction for agriculture in Turkey alone exceeding 36 000 million m^3 in 2004. Also noteworthy is the decline in agricultural water use since 1990 in eastern Europe triggered by the collapse of the Soviet Union and the associated loss of trade (EEA, 2004). This decline suggests the potential for a future increase in irrigated agriculture in this region. In Romania, for example, rehabilitation and modernisation of the irrigation system has been initiated (World Bank, 2007).

6.3.3 *Irrigation demand*

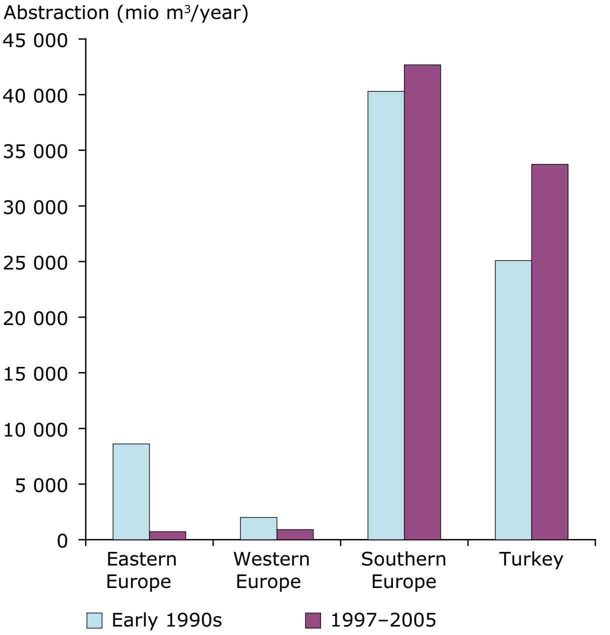
By combining information describing area equipped for irrigation (Map 6.1) with a soil water and crop

Figure 6.1 Trend in 'area equipped for irrigation' (hectares) for selected countries



Source: EEA, based on data from Eurostat data table: Irrigation: Number of farms, areas and equipment by size of farm and region.

Figure 6.2 **Water abstracted for irrigation (million m³/year) in the early 1990s and 1997–2005**



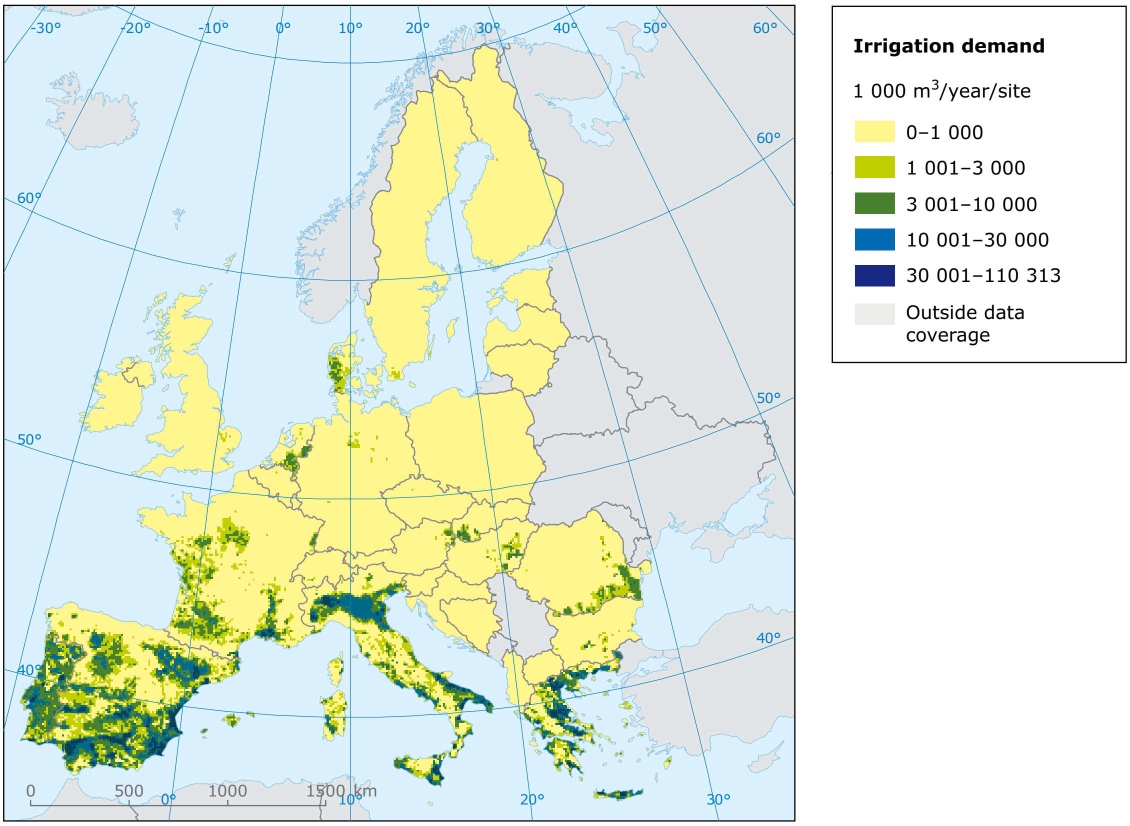
Source: EEA Core Set Indicator CSI 18, based on data from Eurostat data table: Annual water abstraction by source and by sector.

growth model, the European Commission's Joint Research Centre has predicted irrigation water demand for the EU and Switzerland (Wriedt *et al.*, 2008; Map 6.2). The findings reflect the importance of irrigation to agriculture in much of southern Europe and illustrate the approximate volume of irrigation water demand within a defined spatial unit (a 10 km x 10 km cell). Actual abstraction rates will be higher than the demand indicated in Map 6.2 due to inefficiency (losses) in systems supplying crops with water.

6.4 Sustainable use of water for agriculture

Traditional supply-orientated approaches aim to secure a sufficient supply of water for agriculture by, for example, building reservoirs, inter-basin transfers and exploiting new abstraction points from both surface and groundwater. Generally, however, such practices are not sustainable in the longer term and simply exacerbate the adverse impacts of agricultural water use. In contrast, a number of demand-side measures together with

Map 6.2 **Average irrigation demand per site (10 x 10 km cell) in the EU and Switzerland (1 000 m³/year/site over a simulation period 1995–2002)**



Source: Wriedt *et al.*, 2008.

some potentially sustainable supply approaches can address agricultural water use in a more sustainable way. These include the re-using of treated waste water; improving irrigation systems; modifying agricultural practices; implementing policy measures such as water pricing; and establishing farmer advisory schemes.

6.4.1 *Wastewater re-use*

In areas where water is scarce, treated wastewater provides an alternative source of water for irrigating crops. Depending upon the level of treatment, it can be relatively nutrient rich, reducing the need for additional applications of inorganic fertiliser. Examples of successful use of wastewater in agriculture exist within Europe, for example in Gran Canaria, Spain, where 20 % of water used across all sectors is supplied from treated wastewater, including the irrigation of 5 000 hectares of tomatoes and 2 500 hectares of banana plantations (Mediterranean EUWI Wastewater Reuse Working Group, 2007). Similarly, tertiary treatment of wastewater in the city of Vitoria, the administrative capital of the Basque Country, has provided 3 Hm^3/year of irrigation water for nearby agricultural land, with a plan to increase the volume irrigated in the future to 8 Hm^3/year (Mediterranean EUWI Wastewater Reuse Working Group, 2007). Cyprus also re-uses tertiary treated wastewater, more than half of which is used for irrigation of crops, either directly or through the artificial recharge of aquifers. The Government of Cyprus expects wastewater re-use to provide 28.5 % of annual agricultural water demand by 2012.

Although potentially beneficial to water resources, the re-use of wastewater for agriculture raises soil contamination and public health concerns, particularly with respect to pathogens and hazardous substances. As a consequence, the practice is regulated according to quality criteria or standards regarding, e.g. microbial concentrations, often based on established (e.g. World Health Organization) guidelines. In addition, some countries have implemented standards for irrigation techniques and minimum distances to separate irrigation sites from residential areas and roadways. Currently, however, no harmonised Europe-wide regulations exist and the quality standards implemented in different countries vary.

6.4.2 *Improving irrigation efficiency*

Irrigation efficiency can be improved by improving conveyance efficiency, field application efficiency or both.

Conveyance efficiency refers to the percentage of abstracted water that is delivered to the field. There are large differences in conveyance efficiency depending on the type of irrigation network. In open channel networks, efficiency varies between 60 % and 95 %, depending on the quality of maintenance, the lining used and the length of the channels. Average conveyance efficiency of an adequately maintained earthen channel of medium length (200–2 000 m) is estimated at 75 % in Andalucia, while efficiency reaches 95 % for lined channels (Rodríguez-Díaz, 2004). The conversion from open channels to pressurised pipe networks can, therefore, be an important water saving measure. For example in the Cote d'Azur region in France, such a conversion has helped save around 300 M m^3/year (Dworak *et al.*, 2007).

Field application efficiency is the ratio between the water used by a crop and the total amount of water delivered to that crop, indicating how well an irrigation system performs in transporting water to the plant roots. A strong contrast is apparent when comparing furrows with sprinkler and drip systems, with the former having an efficiency of around 55 %, sprinklers 75 % and drip systems 90 % (Dworak *et al.*, 2007). Drip irrigation systems, however, are not suitable for all crops and soil types.

Increased irrigation efficiency can, however, result in either no change or even an increase in water used, when the gains in efficiency simply drive an expansion of the irrigated area. For example, García (2002) reports that drip irrigation technologies that were subsidised in the Valencia region of Spain did not lead to reduced application rates. Furthermore, research in Crete has revealed that the technical efficiency of some farmers using drip irrigation systems is low and they are not fully exploiting the potential water resource savings (OECD, 2006). Any installation of improved irrigation systems needs, therefore, to be accompanied with advice to farmers.

6.4.3 *Modification of agricultural practices*

Crops vary in their resistance to drought, water requirements and the time of year at which the requirement peaks. These factors, together with irrigation management and soil moisture conservation can all reduce crop water use.

Crop tolerance to drought depends partly on the depth of root systems. Crops with deep root systems such as grapes and alfalfa are able to draw upon moisture deeper in the soil horizons than those with shallow roots (e.g. maize and pea) and so cope better during periods of water stress. Crops also vary in their timing of peak water demand. Water demand for maize, for example, is concentrated in the summer months when water stress is at a maximum. In contrast, the cropping calendar of rape, winter wheat and winter barley is centred on the autumn and winter months when there is more water available. The timing of the cropping calendar can also be used as a technique to reduce irrigated water use. Early sowing, for example, can help capture winter rains so that the need for supplementary irrigation is reduced. Early sowing also helps avoid the extreme evapotranspiration rates typical of Mediterranean summers.

Crops vary considerably in their consumption of water. Amigues *et al.* (2006), for example, report that maize, with an average irrigation volume of 1 300 m^3/ha, is the highest water consuming crop in France. By contrast, soybean requires 900 m^3/ha, sugarbeat and potatoes both 800 m^3/ha, and sunflowers and sorghum both 600 m^3/ha. Aside from economical considerations, changing from high water demanding crops to low water demanding (and drought tolerant) crops is an obvious option for reducing irrigation water requirements. The success of such a change is, however, highly dependent on market prices. In addition to changing to less water demanding crop types, there is also potential for returning irrigated land back to traditional rain-fed practices, particularly in regions where water-stress is acute. While such a wholesale change in the approach to farming would clearly make a marked impact on water use, it raises a number of socio-economic issues and may not be economically feasible in some locations.

Deficit irrigation is a technique that aims to reduce the amount of water applied to below the 'theoretical irrigation need' on the basis that the substantial water savings realised outweigh the modest reduction in crop yield. The approach takes advantage of the fact that maximum production does not necessarily lead to maximum profitability. Reducing the irrigation water applied by 40 %, for example, has been shown to result in a decreased yield of only 13 % for wheat (Pereira *et al.*, 2002). For potatoes, water savings of 20 % can be achieved with a yield reduction of around 10 % and for grapevines, reduction in water use ranging from 16.5 % (rainy years) to 53 % (dry years) produced no significant impact on the grape yield or the quality of the must (Battilani, 2007). For maize, limited reduction in yields due to water savings of up to 20 % would be entirely compensated by reduced irrigation and drying costs (Amigues *et al.*, 2006).

Improving the timing of irrigation so that it closely follows crop water requirements can lead to significant water savings (Amigues *et al.*, 2006). The approach does require, however, that farmers are well trained and familiar with issues such as temporal changes in crop water demand and the estimation of soil moisture. Nevertheless, several research initiatives have shown encouraging results. For example, the 'Hagar' project (EC, 2007c) aimed to facilitate decision-making in irrigation with the help of on-site, real-time microclimatic and soil humidity sensors. The project was undertaken on agricultural land overlying an over-exploited aquifer in Spain, trained farmers and technicians and realised water savings.

With other highly water demanding crops like maize or beetroot the results have also been marked, with water savings of around 20–30 % compared to normal practices (WWF, 2006a). Other studies have looked into the environmental impact of irrigating olive trees. Currently, the irrigation of olive plantations often has little agronomic foundation in terms of the quantities and timing of water applications; many farmers apply more water than is necessary or desirable for the health of the plantation and state of the soil. In Andalucía, there have been some positive initiatives from the authorities, farm associations and researchers to promote a more rational use of irrigation in olive farming (Beaufoy, 2000).

No-tillage farming involves leaving the soil intact and covered by crop residues following harvesting. Compared to traditional tillage methods, this practice has been shown to reduce water loss through evapotranspiration, thereby maintaining higher soil moisture levels and reducing the amount of water required from irrigation (Christensen *et al.*, 1994).

6.4.4 Agricultural policy

Recent reforms (Agenda 2000 and the mid-term review) of the CAP have decoupled agricultural subsidies from production levels and therefore have potential to reduce the use of water in agriculture. The reforms also involve implementing a 'cross-compliance' mechanism that requires all farmers receiving direct payments under various schemes to comply with a set of 'statutory management requirements' in the areas of environment, animal welfare, animal diseases and public health. Payments are also dependent upon farmers keeping their land in 'good agricultural and environmental condition'. A sound management of water resources is encompassed by these requirements, with the issue being given further emphasis in the 2008 CAP 'health check', which includes the requirement to respect authorisation procedures for using water for irrigation.

In addition to decoupling and cross compliance, the CAP's rural development regulation includes the implementation of agri-environment and farm modernisation measures. These involve payments to farmers that carry out specific agri-environmental commitments that go beyond usual good farming practice and include the improvement of irrigation efficiency.

6.4.5 Water pricing within agriculture

Water pricing is a potentially effective mechanism for influencing the volume of water used for irrigation. Its implementation across Europe has been given momentum by the Water Framework Directive principle of 'cost recovery' for water services. Water pricing can trigger reduced water use via a number of possible farmer responses, including improving irrigation efficiency, reducing the area of irrigated land, ceasing irrigation and modifying agricultural practices such as cropping patterns and timing of irrigation.

To date, however, water pricing has been applied only on a limited scale in European irrigation districts and often coupled with other instruments such as quotas. Consequently, little information is available to assess the success and limitations of water pricing in agriculture and to identify optimal implementation practices. One exception is that of the Guadalquivir river basin in Spain where, in the Genil Cabra and Fuente Palmera irrigation co-operatives, a new water charging structure was implemented to replace the old area-based charge (Maestu, 1999). The new approach included both a fixed and variable charge linked to water use, with farmers paying, on average, significantly more than under the original area-based approach. This has resulted in a 30 % reduction in water consumption (for the same crop types) equating to approximately 2 000 m^3/ha of water saved per year (Maestu, 1999).

To ensure that they provide an incentive to conserve water, agricultural water pricing structures will need a variable element (as opposed to a flat rate) whereby cost rises with volume used (EC, 2000; OECD, 2008). For example, Rodríguez-Díaz (2004) showed that those irrigation districts in the Guadalquivir basin, Spain, with pricing based on the volume of water used consume, on average, 10–20 % less than those districts with flat rate pricing, regardless of the level of the flat rate. Similarly, Hernández and Llamas (2001) report that farmers charged at a volumetric rate used 25 % to 35 % less water than those facing a flat rate charge.

Conversion from flat to volumetric rates requires the installation of water meters and while there is currently a general lack of such devices their numbers are increasing rapidly. In the Adour-Garonne river basin in the south of France, for example, the number of water meters has drastically increased since the mid-1990s due to financial support from the regional water agency (Dworak *et al.*, 2007).

It should also be noted that an increasing water price does not always lead to reduced agricultural water use, particularly when the water bill accounts for only a small proportion of farmer's total production costs or income; when alternative crops or irrigation practices are not available due to technical, social or economic constraints; or when the bulk of the total water charge consists of fixed costs (Rieu, 2006). In the Duero region in Spain, where the number of crop types is limited, Gómez-Limón *et al.* (2007) report that farmer incomes need to decrease by 25 % to 40 % before price increases have an impact on water use. In irrigation systems where water efficiency is already high or where high value crops are grown, the price 'elasticity' is likely to be low (Dworak *et al.*, 2007).

There are situations where water pricing may not lead to a significant reduction in agricultural water use. But in general a pricing approach that accounts for local environmental, economic and institutional conditions will provide a strong incentive for a sustainable use of water, ensuring that environmental objectives are met more cost-effectively.

6.4.6 Advice, education and information dissemination

Technological and policy measures need to be accompanied by advisory, educational and information dissemination activities aimed at farmers in order to achieve optimal outcomes with respect to agricultural water use. In general, more farm advisory systems are needed throughout Europe and they must be made accessible to a greater number of farmers (Dworak *et al.*, 2006). In this respect, the rural development programmes of the CAP can play a key role, since advisory services are one of the measures proposed in the rural development regulations.

Box 6.1 Case study — the Júcar River Basin, Spain

The Júcar River Basin in south-east Spain covers an area of approximately 43 000 km^2 and encompasses part of four autonomous regions: Aragon, Castilla La Mancha, Catalunya and Valencia. Forest and semi-natural land cover 50 % of the basin and non-irrigated agriculture encompasses about 40 %. Irrigated agriculture covers 8 % of the basin, predominantly in coastal areas and the Mancha region, but accounts for 79 % of the total water use across all sectors — 3 625 hm^3/year in 2001 (CHJ, 2004). The main irrigated crops are mandarins (27 %), oranges (19 %), barley (6 %), maize (6 %), rice (4 %) and wheat (4 %). The Júcar basin also has 45 000 ha of wetlands including four that are included under the Ramsar Convention on Wetlands.

The Júcar basin has a Mediterranean climate, with an average annual precipitation of 500 mm, which varies markedly between 250 mm/year in the south to around 900 mm/year in the north. Rainfall is typically concentrated into a few intense events of short duration, particularly in the autumn when it can exceed 300 mm in 24 hours. This typical pattern of rainfall contrasts with the timing of agricultural water demand, which peaks during the summer months. To address this imbalance, numerous dams regulate river flow throughout the region thereby prolonging the supply of water. Both surface and groundwater sources supply water for agricultural purposes, as do two (Jacarilla and El Campillo) of the 17 desalination plants in the Júcar basin, which contribute more than 3 700 000 m^3/year (CHJ, 2004).

Irrigated agriculture has increased steadily over recent decades throughout the Júcar basin, growing from less than 300 000 ha in the mid-1970s to in excess of 350 000 ha in the late 1990s. Since then, the irrigated area has remained relatively stable with fluctuations between 320 000 and 355 000 ha. Some areas of the basin have experienced a more rapid growth; irrigated crops in the Castilla La Mancha region, for example, increased by 86 000 ha between 1999 and 2005. In particular, the area of irrigated olive trees, traditionally grown as a rain-fed crop, nearly tripled over this period, whilst the area of irrigated vines doubled (MAPA, 2008).

The growth of irrigated area in the 1990s was driven, in part, by the CAP, which provided 'direct payments' for irrigated crops across the region, thereby increasing farmer incomes. This helped make costly investment schemes affordable, for example the improvement of irrigation equipment and general infrastructure. CAP support of rural development programmes, implemented under national irrigation plans, also influenced the growth of irrigated agriculture.

The expansion of irrigated agriculture in the Júcar basin has ensured that farming has remained financially viable in rural areas that might otherwise be at risk of abandonment and helped to maintain the socio-economic stability of the region. However, it has also had a clear negative impact on water resources. Water levels in the Mancha Oriental aquifer, which partly underlies the Castilla La Mancha region, dropped significantly between 1985 and 2001, and are continuing to decline at present (CHJ, 2005; CHJ, 2007). In addition, the volume of discharge from the aquifer to the Júcar River has markedly diminished since the early 1970s (CHJ, 2004).

The acute pressure on the water resource in the Castilla La Mancha region led, in 1999, to the establishment of an Irrigation Advisory Service for Farmers (SIAR) via a cooperation agreement between the University of Castilla-La Mancha and the regional government (Ortega *et al.*, 2005). The overall aims of SIAR are to improve farmer capacity and awareness, decrease production costs and make irrigated agriculture in the area more sustainable. The total estimated cost of the SIAR service to each farmer is about EUR 3/ha/year.

During the 2001–2003 campaign around 500 farmers directly collaborated with SIAR, and more than 1 200 received advice indirectly through irrigation district administrations and cooperatives (Ortega *et al.*, 2005). Much of SIAR's work focuses on the provision of advice regarding irrigation scheduling, taking into account the water requirements specific to each crop type. Central to this is the calculation of a daily water balance using data from a network of automatic weather stations. The evaluation of irrigation systems is also a key part of the SIAR programme and by 2005 more than 875 on-farm evaluations had been made, leading to improved irrigation efficiency (Ortega *et al.*, 2005). Aside from direct on-farm advice, SIAR disseminates information via websites, including daily advice on the net water requirements by crop type. In addition, information is made available via weekly faxes to farmer associations and cooperatives and by holding workshops.

In all pilot areas where water resources were scarce and water costs high, a high proportion of farmers have adhered to the irrigation advice (Ortega *et al.*, 2005). In contrast, in areas where water is not so scarce and farmers pay for water by surface area irrigated rather than volume consumed, the adherence to advice from SIAR has been low.

In addition to advisory programmes, national irrigation plans have been implemented within the Júcar basin with the objectives of saving water and modernising irrigation infrastructure, for example installing on-farm sprinkle/trickle irrigation systems. Furthermore, a specific drought action plan has been established for the Júcar basin (CHJ, 2006). It encompasses a wide range of actions to reduce abstraction, including more detailed management of the water resource, improved monitoring and use of alternative sources such as desalination. Overall, a mix of measures, including expanding the advisory service, may be the best approach to addressing unsustainable agricultural water use in the Júcar basin.

7 Conclusions on future water resource management in Europe

Increasing problems of water scarcity and drought clearly indicate the need for a more sustainable approach to water resource management across Europe. Such an approach will require a marked shift towards demand-side management, implying a key role for measures that control or improve the efficiency of water use. According to this approach, any expansion of traditional infrastructure-based water supply would occur only when all other options have been exhausted.

A more equitable approach to abstraction will also be necessary, addressing not only the competing requirements of each sector involved but also the requirements of the aquatic environment and the need to achieve and maintain healthy freshwater ecosystems. Implementing such a management approach successfully would not only help adapt to climate change but also contribute to lower energy consumption, since water and energy use are usually closely linked.

The need for a more sustainable and integrated approach to managing water resources in Europe is already reflected in water-related policy and legislation. The WFD, for example, requires the 'promotion of sustainable water use based on a long-term protection of available water resources'. To this end, the 'registration and control of abstraction of both surface and groundwater' is identified as a key measure. The European Commission has also recognised the challenge posed by water scarcity and droughts in a 2007 communication (EC, 2007a). The communication outlines the severity of the issue and presents a set of policy options to address water scarcity and drought Europe-wide. Successfully achieving demand-led water management across Europe will potentially require the implementation of a number of differing policies and practices, as outlined below.

7.1 Water pricing

Introducing water pricing across all sectors will be critical to achieving sustainable water use. The WFD recognises this, requiring that pricing provide adequate incentives to use water resources efficiently and recover the full cost of water services. Full cost recovery not only encompasses the cost of water supply, maintenance and new infrastructure but also environmental and resource costs. As such it reflects the 'water user pays' principle.

Effective water pricing needs to be based, at least in part, on the volume of water used, rather than adopting a flat-rate approach. To this end, water metering plays a key role and must be implemented widely across all sectors. Successful water pricing will require a good understanding of the relationship between price and use for each sector and needs to account for local conditions. In line with the Millennium Development Goals guaranteeing universal access to clean water and sanitation, however, pricing must not mean that anyone should compromise personal hygiene and health in order to pay their water bill.

7.2 Drought management plans

Drought management plans provide a powerful tool to alleviate the impacts of drought and reflect a positive shift from a 'crisis response' to a 'risk management' approach. Plans developed so far within Europe have included, for example, the mapping of water stress, the identification of warning or alert systems and sector-specific measures, such as temporary restrictions on irrigating water-intensive crops. The value of implementing drought management plans at river basin scale has been recognised within the WFD. Ensuring widespread development of such plans across Europe will require efforts to foster information sharing on best practice in drought risk management.

7.3 Water efficiency and conservation

Implementing technologies and practices that either conserve water or use it more efficiently plays a key role in the demand-side approach to water management.

With respect to agriculture, improved efficiency can be realised by improving the methods by which water is supplied to crops; pressurised pipe networks are more effective than gravity-fed open channels, for instance. Drip and sprinkler systems are also more efficient than furrows in delivering water to plant roots. Evidence exists, however, that in some cases improvements in irrigation efficiency have simply driven an expansion of the area irrigated, resulting in either no reduction or even an increase in total water use. The relevant authorities must ensure that this does not occur.

A change to less water demanding crops, including those that are more tolerant of water stress, can promote reduced agricultural water use. Reductions can also be achieved by improving the timing of irrigation, using monitoring or estimation of soil moisture to closely follow the crop water requirement on a daily basis and, through implementing deficit irrigation techniques. Growing crops whose water demand peaks prior to the summer months can also reduce maximum water stress at the height of summer.

Demand for energy crops could increase agricultural water use. In areas of water scarcity, guidance and, where necessary, intervention by authorities is required to ensure that the introduction of new energy crops does not boost water use. Instead any such introduction should be used as an opportunity to reduce agricultural water use by using low water demand or drought tolerant energy crops.

Both national and EU funds, including the CAP, can potentially play an important future role in implementing measures to reduce agricultural water use. Successful outcomes are most likely to be achieved, however, if advisory, educational and information dissemination services are also provided for farmers.

The introduction of successful water saving measures is reported across various industrial sectors in Europe, although significant potential remains for a greater implementation of such practices. Recycling of industrial wastewater has an important role in this respect, not only in reducing water use but also the subsequent discharge of wastewater.

With respect to public water supply, the most modern of the commonly used domestic appliances or fittings, including washing machines, dishwashers, toilets and showers, are significantly more water efficient than their predecessors. A challenge remains, however, to increase the uptake and use of these modern technologies across the whole of Europe. Both regulation, in terms of standards, and consumer awareness play a role in this respect. Leakage in public water supply systems remains significant in many European countries, despite the general availability of modern leak detection technologies. Tackling leakage may require the imposition of fines where agreed reduction rates are not met.

7.4 Raising awareness

Achieving more sustainable use of public water supplies will depend strongly upon raising public awareness of water conservation issues. Various means are available to inform domestic, business and tourist water consumers. They include websites, school education programmes, local authority leaflets and the mass media. Eco-labelling of appliances and eco-certification of, for example, tourist hotels can also play an important role in raising awareness, helping consumers to make informed choices about water efficiency and conservation.

The concept of 'virtual water' describes the amount of water required to produce a particular good or service (Allan, 1996) and encompasses virtual water flows between countries where products are traded internationally. Efforts to broaden public understanding of the concept would, in principle, improve consumer awareness of water use, highlighting the significant variation in water expended to produce different agricultural and industrial products (Hoekstra and Chapagain, 2007). Care is required in using virtual water as an information tool, however, since the approach lacks methodological consistency and does not provide any indication of whether water used for a particular product fell within sustainable abstraction limits at its source (Frontier Economics, 2008) or how much was returned to a waterbody.

7.5 Tackling illegal water use

While reliable quantitative information on the issue is scarce, it is clear that the illegal abstraction of water, particularly from groundwater and often for agricultural purposes, is widespread in certain areas of Europe. Addressing illegal water use is crucial but represents a major political and technical challenge. Monitoring is required to detect illegal wells and authorities have to follow up detected cases with fines or penalties sufficiently severe to deter further illegal abstraction. Surveillance is also required to ensure continued compliance.

7.6 Alternative supplies

Demand-side measures based on conservation and improved efficiency represent the optimal approach to water resource management across Europe. In some regions where this approach is adopted, however, demand may still exceed availability and it may also be necessary to consider supply-side measures. Where this is the case, such measures must be subject to rigorous assessment of their environmental impacts. Potentially more sustainable supply-side measures, notably re-use of water and treated wastewater, may be preferable to the more traditional approaches of reservoirs and water transfers.

Rainwater collected from roofs and impervious surfaces, and greywater from baths, showers, washbasins and the kitchen, can be used for non-potable purposes such as the watering of gardens. Both practices help to diminish demand from the public water supply and, therefore, the energy requirements associated with providing clean water. Furthermore, they have minimal detrimental environmental impacts. Water recycling is also increasingly implemented in various industrial sectors leading to clear improvements in water use efficiency and reduced water expenses.

The re-use of treated waste water, although not currently widely practiced, is growing across Europe, particularly for the irrigation of crops and golf courses. Its use within industrial plants is also now reported. Significant potential exists for much greater use of treated wastewater.

7.7 Desalination

Desalination increases the total available freshwater resource and, in this respect, may be preferable to further depletion of the surface and groundwater stocks. Detrimental environmental impacts are associated with desalination plants, however, in particular their energy consumption and the production of highly concentrated brine that may be released into sensitive marine waters. Furthermore, expanding supply from desalination plants does not provide any incentive to either reduce water use or improve the efficiency of use. Decisions on the suitability of future desalination plants need to be addressed on a case-by-case basis, accounting for all environmental and economic issues.

7.8 Information requirements

Moving towards sustainable water resource management requires that reliable and up-to-date information is available at appropriate spatial and temporal scales across Europe. Such information has many benefits including providing an improved overview of the causes, location and scale of water stress; helping identify trends; facilitating the evaluation of measures implemented to address unsustainable water use; and assisting EU citizens to engage in water issues.

Information is required not only at the river basin scale but also, critically, on a monthly or seasonal basis, since annual averages are unable to convey fully the peak levels of water stress — normally experienced during the summer months. Unfortunately, the provision of data to Eurostat and the Organisation for Economic Co-operation and Development (who together organise the collation of data that has enabled pan-European assessment to date) has not been at the optimal spatial or temporal scale. In addition, national assessment and monitoring programmes frequently possess significant information gaps and are seldom harmonised in terms of the type of data collected and the methods employed. Furthermore, information describing the socio-economic impacts of water scarcity and drought, together with the cost-effectiveness of potential measures is currently either limited or not accessible across Europe.

The recently established joint reporting initiative of the EEA, Eurostat and the European Commission aims to address these shortcomings and improve water information Europe-wide. Member States will voluntarily submit regular data on both water availability and multi-sectoral water use. This information will be generated at a harmonised river basin scale and on a seasonal basis. While potentially raising a challenge to Member States' environmental and statistical reporting and their interaction with the relevant sectoral authorities, the initiative is crucial to achieve pan-European assessment of water resources. This reporting initiative will be complemented by a project from the Joint Research Centre to develop an observatory and early warning system for droughts across Europe.

In a related development, the EEA has also begun to develop river basin scale water balances for Europe based on the United Nations system of environmental-economic accounting for water (SEEAW, 2008). The approach is able to use both measured and modelled data and will provide accounts on a monthly basis, reflecting water stress throughout the year and the probability of its occurrence. The approach also enables the impact of water management scenarios to be explored. Moreover, the water account methodology has the potential to help distinguish the impact of water scarcity on observed water availability from that of drought.

Finally, information describing water resources, whether from voluntary reporting initiatives or compliance data provided under legislation, can now be collated and disseminated within the Water Information System for Europe (WISE) — a tool recently developed to serve as the single entry point for water information in Europe.

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European Environment Agency

Water resources across Europe — confronting water scarcity and drought

2009 — 55 pp. — 21 x 29.7 cm

ISBN 978-92-9167-989-8
EEA Report series: ISSN 1725-9177
DOI 10.2800/16803

TH-AL-09-002-EN-C
DOI 10.2800/16803

Price (excluding VAT): EUR 15.00

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ISBN 978-92-9167-989-8

9 789291 679898

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