Water Policy Briefing

Issue 19

Putting research knowledge into action

Choosing Appropriate Responses to Groundwater Depletion

Billboard in Luancheng City, China, advising citizens to conserve water: "Cherish Water and You Cherish Life". PHOTO CREDIT: ELOISE KENDY

Heavy use of groundwater leading to steady declines in water tables is a problem increasingly witnessed in many parts of the world. In an attempt to reverse this trend, water policy experts and resource managers often advocate improving irrigation efficiency, an apparent solution that is also seen as being politically palatable. Such approaches, however, are not always effective. A holistic study of a hydrologic system is needed to find out how best to deal with groundwater depletion—what the optimal solutions are.

IWMI
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Groundwater declines: looking for the right solutions

With growing populations, changing weather patterns, and increasing pollution of surface water bodies, countries across the world are relying more and more on finite groundwater reserves built up over centuries, for household, agricultural, and industrial needs. Although addressing water shortages in the short term, groundwater exploitation brings with it its own host of problems. It can cause salt water intrusion into fresh water aquifers and subsidence of the land surface.

Governments are quick to turn to **improving water efficiency** as the best solution to the problem, but are too often disappointed. Research is increasingly highlighting that in devising water management strategies to conserve water and halt the decline of groundwater levels, policymakers must conduct **holistic studies of hydrologic systems** to find appropriate solutions that will result in real water savings. What's needed then is not a simple 'one size fits all' policy or solution, but varying management approaches to suit specific situations.

The concept of **hydronomic zones,** which categorizes a hydrologic system into different zones—each having its own water-related issues—could be a useful tool in this exercise.

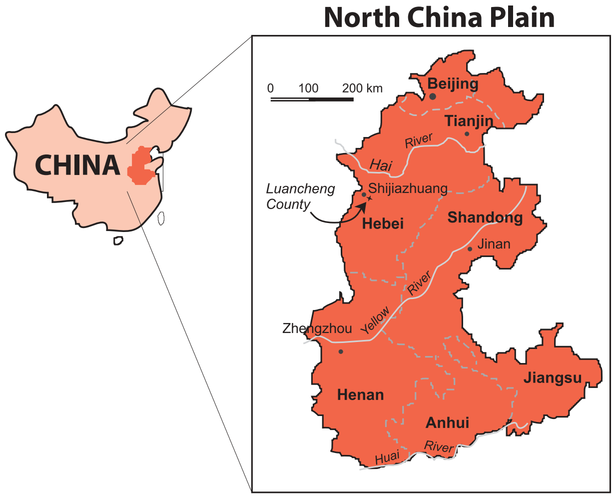
Examining contradictions in the North China Plain

The North China Plain is China's most important agricultural centre, producing more than half the country's wheat and a third of its maize. Here, the deficit between rainfall and crop requirements has been met by irrigation from aquifers underlying the plain. Pumping water from the aquifers has led to the continued decline of groundwater levels despite improved irrigation efficiency and reduced pumping.

This seeming contradiction has puzzled water policy experts and resource managers and provided the impetus for IWMI's study in the Luancheng County located in the Hai River basin, one of the three rivers making up the North China Plain (fig.1). The study examined the nexus between agricultural policies in the area, water management approaches, and actual water use, in an effort to explain the steady decline in groundwater levels and to find appropriate solutions to halt this decline.

The North China Plain is 320,000 km^2 in extent and is home to more than 200 million people. It is bordered by mountains on the west and the Yellow Sea on the east. Three rivers drain into the plain (fig.1). The climate is temperate and monsoonal, with cold, dry winters and hot, humid summers. The plain is China's most important centre of agricultural production, producing more than half the country's wheat and a third of its maize. Yet, the shortage and seasonal distribution of water are two key factors that inhibit agriculture. Annual rainfall averages between 500 mm in the north and 800 mm in the south. The typical winter wheat/summer maize cropping pattern which is currently practised consumes 660mm to 920mm of water annually.

Figure 1. Location of Luancheng Country within the North China Plain



This Water Policy Briefing is based on *Policies Drain the North China Plain: Agricultural Policy and Groundwater Depletion in Luancheng County, 1949 – 2000* (IWMI Research Report 71) by Eloise Kendy, David J. Molden, Tammo S. Steenhuis, Changming Liu and Jinxia Wang and on *Hydronomic Zones for Developing Basin Water Conservation Strategies* (IWMI Research Report 56) by David J. Molden, R. Sakthivadivel and Jack Keller. The full text of these reports is available at *www.iwmi.cgiar.org/pubs/rrindex.htm*

Agricultural policies and water management in the North China Plain 1949 – 2000

Agricultural policies and related water resource development policies have undergone four distinct phases in the Luancheng County since the formation of the People's Republic of China in 1949. The central goal of agricultural policy—food self–sufficiency—has however remained constant throughout these four phases. And going hand in hand with this policy is the requirement for a stable or increasing supply of water for irrigation.

Before 1949 there was no major irrigation development and most of the crops were rainfed. Only one crop per year could be produced. The area's aquifers were recharged by seepage from three river channels, and there was also periodic flooding. During the Nation Rebuilding phase (1949 – 1958) much effort was put into irrigation works and this cut all stream flows into Luancheng except for the wastewater from Shijiazhuang City. Thus, ironically, the development of irrigation systems left the county drier than before.

In the Commune Era from 1958 to 1978, groundwater irrigation began in earnest and led to improved crop yields and continuous cropping with two harvests each year. Even at this early stage, declines in the water table were evident.

In the Early Reform period (1979 – 1984), production which until then had been managed collectively, was decollectivized. This had two significant impacts. Firstly, farmers had an incentive to work more efficiently, and an immediate increase in grain production was seen. Secondly, irrigation efficiency improved. Groundwater pumping for irrigation in Luancheng County decreased from about 1,020 mm/year in 1976 to about 390 mm/year in 1996.

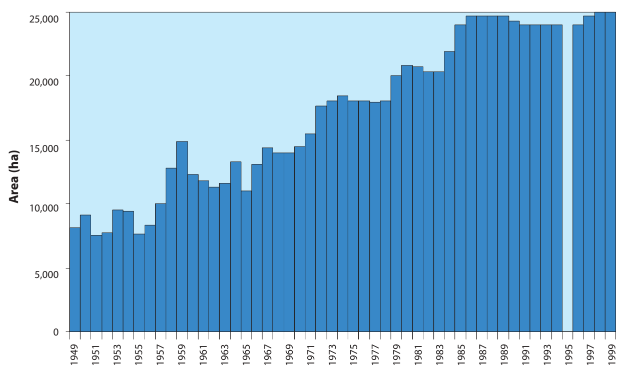
Nevertheless, water table declines continued and concerned regional authorities formulated regulations to strengthen groundwater management. However, these measures were not implemented at local level. On the contrary, subsidies were provided for the construction of wells, facilitating an expansion in winter wheat production (fig. 2) and a shift from the relatively drought resistant cotton to irrigated maize (fig. 3).

The Later Reform period (1985 – 2000) saw an increasing demand for irrigation-intensive cash crops. There was also increased competition with the city for groundwater resources. Shijiazhuang city depends largely on groundwater, and increased pumping means that water that would naturally have flowed down to the aquifers underlying the Luancheng County is diverted for use by the city. Residents have had little choice but to dig deeper wells in search for water.

The effect: water use trends and groundwater decline

As agricultural policies and water management strategies evolved over the years, water use trends also changed accordingly. With increased winter wheat cropping and a shift from cotton to more irrigation-intensive maize, an increase in groundwater use that would mirror the cropping patterns could be expected. However, the reality is quite different. Contrary to expectations, groundwater pumping did not increase with the increase and change in cropping. Even more surprisingly, pumping rates actually decreased during the late 1970s to the early 1980s before finally stabilizing in the 1980s (fig. 4). Yet, there has been a steady decline in groundwater levels throughout the period under study. How does one explain these seeming contradictions?

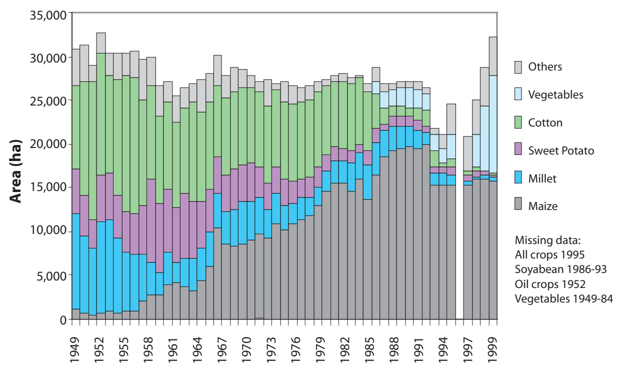
Figure 2. Cropping history of Luancheng Country, 1949-1999—winter wheat sown area



Cropping history of Luancheng County, 1949-1999 – winter wheat sown area.

Source: Shijazhuang Statistics Bureau (1949-2000)

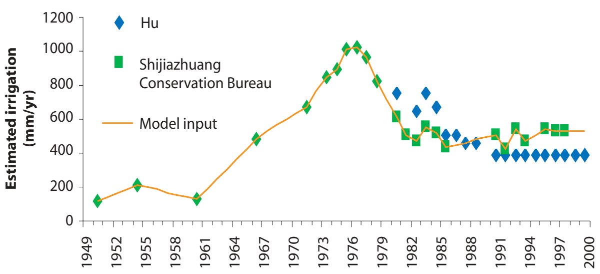
Figure 3. Cropping history of Luancheng Country, 1949-1999—summer crop sown areas



Note: 'Other' summer crops include orchards, sorghum, oil crops and soyabeans.

Source: Shijazhuang Statistics Bureau (1949-2000)

Figure 4. Irrigation history of Luancheng Country, 1949-1999—estimated pumping for irrigation



Note: 'Pumping' in the 1950s was primarily hauling, rather than pumping, from shallow, brick-lined wells. 'Model Input' indicates groundwater pumping and irrigation values used to calculate annual water balances.

Sources: Hu, Chanseng, Chinese Academises of Science, personal commun.; Shijiazhuang Water Converstion Bureau (1949-1999)

The cause: the policy–water use nexus

IWMI's study used a water balance approach to try and find the answer. It is a simple accounting method used to quantify hydrologic changes. The soil water balance and the groundwater balance in Luancheng County were both studied (fig. 5).

The study concluded that the continued decline in groundwater levels is due to the longstanding agricultural policy of achieving food self-sufficiency by continually increasing the irrigated area, coupled with the use of groundwater to supplement precipitation. Even more interesting is what the study reveals about the connection between increasing irrigation efficiency and groundwater levels. In Luancheng County, irrigation efficiency has increased, causing more than a 50% decrease in groundwater pumping since the 1970s (fig. 4). However, groundwater levels continue to drop steadily. Because excess irrigation water seeps through the soil back to the aquifer underlying irrigated areas and replenishes the water supply, the only significant inflows and outflows to the system are through precipitation and crop evapotranspiration. As long as these two factors remain constant, increased irrigation efficiency will save no water. Instead, other options like reducing the length of the growing season and reducing the extent of irrigated land need to be considered to halt the decline of groundwater levels.

Thus, simply changing the amount of water applied for irrigation will not affect the rate of groundwater depletion. The only other variables are rainfall and evapotranspiration. Clearly then, if there is to be any reduction in groundwater depletion and any real water savings, there must be a decline in

All water balance equations have the form:

Inflows – Outflows = ΔS (1)

A soil water balance has the form:

$P + I - ET - R = \Delta S = 0$ (2)

And a groundwater balance has the form:

$R - I = \Delta S$ (3)

where P is precipitation; I is irrigation water pumped from the aquifer and applied to crops; ET is crop evapotranspiration; R is drainage from the soil profile which then recharges the aquifer; ΔS is the change in groundwater storage, as evidenced by water table declines.

In Luancheng County the average precipitation (P) for the study period was 460 mm/yr; the average evapotranspiration (ET) from the crops was 660 mm/yr. Substituting these values into the equations above we have:

$P + I - ET - R = \Delta S = 0$ (2)

$460 + I - 660 - R = 0$

$R = I - 200$

$R - I = \Delta S$ (3)

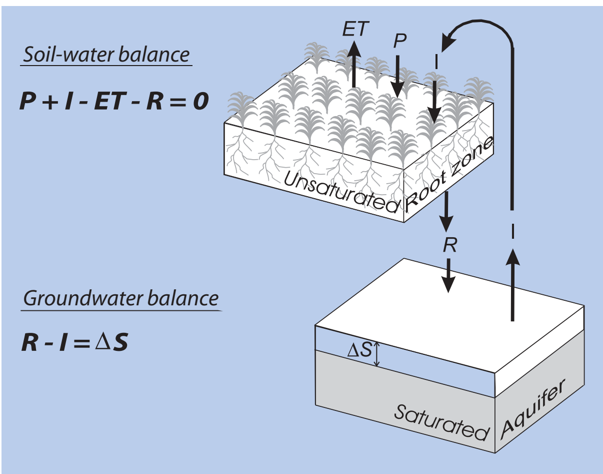
$I - 200 - I = \Delta S$

$\Delta S = -200$

From the soil water balance (2) it is seen that drainage from the soil profile is 200 mm/yr less than the quantity of water applied as irrigation. This will remain so, as long as rainfall and evapotranspiration remain constant.

Examination of the groundwater balance (3) shows that irrespective of the amount of water pumped from the aquifer for irrigation, the groundwater storage will decrease by 200 mm/yr and this equates to an annual drop in the water table of 1 m.

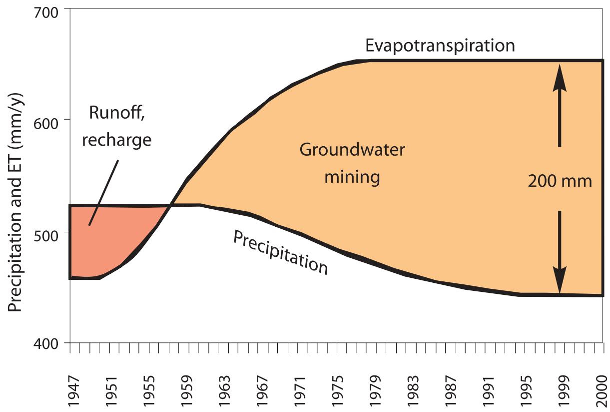
Figure 5. Generalized soil-water and groundwater balances of Luancheng Country



Note: ***P*** is precipitation, ***I*** is irrigation water pumped from the aquifer and applied to crops; ***ET*** is crop evapotranspiration; ***R*** is drainage from the soil profile which recharges the aquifer; Δ***S*** is change in groundwater storage, as evidenced by water-table declines.

evapotranspiration. This conclusion is further borne out by the relationship between rainfall, evapotranspiration and resulting depletion in groundwater over the study period (fig. 6).

Figure 6. General relationship between precipitation and evapotranspiration for cropland in Luancheng Country, 1947-2000



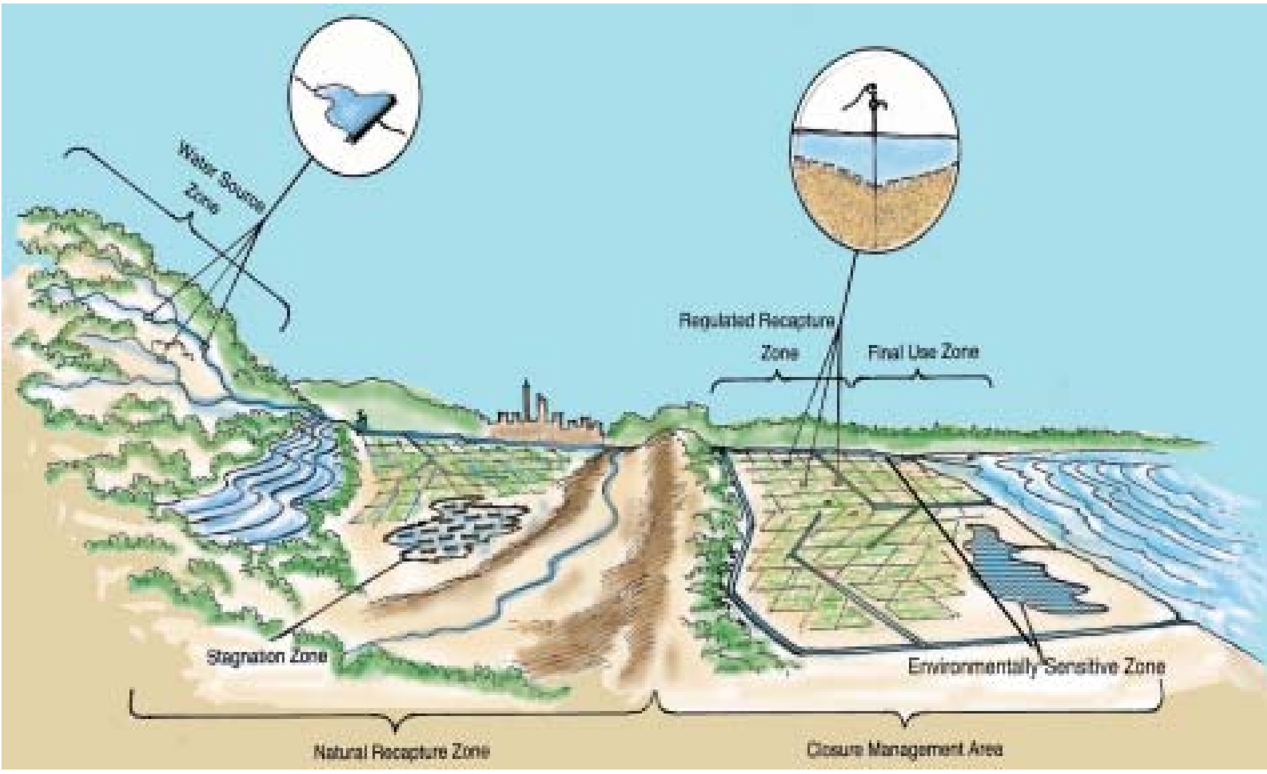
In the early years before irrigation development, precipitation exceeded evapotranspiration and the excess water recharged the aquifer, sometimes even causing it to overflow. As irrigated areas grew and the number of crops harvested each year rose, evapotranspiration increased until it exceeded rainfall (fig. 6). It was at this point that groundwater mining began and since that time the amount of groundwater mined has been the difference between rainfall and evapotranspiration, irrespective of the amounts pumped out of the aquifer. As long as this difference remains virtually constant the rate of groundwater depletion too will remain constant.

Taking into consideration the entire hydrologic system, including both the soil profile and the underlying aquifer, has uncovered a simple but nevertheless vital factor that has been overlooked by water policy experts and resource managers over the years—that as long as crop evapotranspiration remains constant or increases there can be no reduction in the rates of groundwater depletion.

The answer lies therefore in methods that will either maintain or reduce the rates of evapotranspiration. The holistic study of the hydrologic system points us in the right direction in the search for these solutions.

A concept that is useful in studying hydrologic systems is that of hydronomic zoning. A hydrologic system such as a river basin is divided into hydronomic (*Hydro* water + *nomus* management) zones which are defined primarily according to the destination of the drainage outflow from water uses. Thus there are zones where water can be reused and those where it cannot, because of location and quality. Expanding this further, each hydrological system can be classified into all or some of the following zones: water source, natural recapture, regulated recapture, stagnation, environmentally sensitive and final use zones (fig. 7).

Figure 7. Hydronomic Zones in a river basin



Description of zones

Water source – area where excess rainfall provides runoff or groundwater recharge for use downstream. The area where most of the runoff or water supply originates.

Natural recapture – area of the basin where surface and subsurface drainage water flows are naturally captured by river systems or channel networks. The water that is diverted but not depleted by evaporation in a use cycle will be naturally recaptured and available for reuse.

Regulated recapture – area where reuse of surface water runoff or deep percolation water can be regulated. Return flows are captured by a drainage network separate from distribution network and water does not naturally return to the system.

Stagnation – isolated area where drainage is insufficient for removal of leached salts and excess water. Usually consists of rising water tables and waterlogged and/or salinized areas.

Environmentally sensitive – area where there is a requirement for water for ecological or other environmentally sensitive purposes. Wetlands are a classic example.

Final use – area with no further opportunity for reuse of water, typically situated at the terminal end of the basin.

Conditions within zones: whether or not there is salinity or pollution loading or the opportunity of groundwater storage

The classification of the system into the different hydronomic zones helps identify the best methods of saving water since each zone has its own best set of water saving measures. In identifying these sets of measures, factors that must be accounted for are the extent to which the system has excess water available for depletion, the level of groundwater dependence, and the extent of pollution and salinity loading.

A selection of possible answers

It has been proven that groundwater declines will slow only when water depletion decreases and will reverse only when net inflows exceed net outflows. Either there must be an increase of inflows or a decrease of outflows. In the Luancheng County what this essentially means is that precipitation must exceed evapotranspiration, i.e. measures must be taken to decrease evapotranspiration to a level less than annual precipitation.

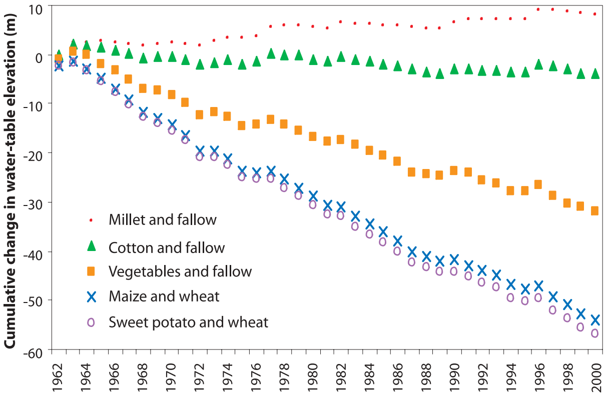
The most popular and the most politically acceptable way of attempting to achieve this is to increase irrigation efficiency. However, IWMI's study has clearly shown that this will not always be effective. Examining a hydrologic system as a system of hydronomic zones has shown that efficiency technologies will not be effective in natural and regulated recapture zones with groundwater storage and low salt build up. If there is significant salt build up or pollution in a regulated recapture zone, efficiency technologies will be useful in controlling pollution. These methods will also be useful where there is no significant recharge of the aquifer or where the recharge is heavily polluted or to decrease energy use. In a natural recapture zone such as Luancheng County irrigation efficiency will not be effective in stemming groundwater decline. Thus, a variety of other options have been suggested and considered.

A measure that is often suggested for water conservation is water price increases to increase irrigation efficiency. In the case of the Luancheng County this might not be appropriate since in this case, reducing pumping but irrigating the same area will not stop groundwater decline. Rather, what is required is a change in land use; whether this will ensue from higher prices is debatable.

Aside from irrigation efficiency there is a variety of water saving technologies which are put forward as one of the solutions. Some of these technologies may exacerbate the problem if used inappropriately. For example, while sprinkler irrigation will save energy and allow for more precise application of water and fertilizers leading to higher yields, it will not always be effective in reducing groundwater decline and in some situations might even aggravate the problem if farmers decide to irrigate more crops with the water they save. Technologies that reduce evaporation such as the use of mulching and the establishment of greenhouses would be ideal for Luancheng County.

Changing the cropping pattern is one possibility which needs to be carefully looked at. Adopting less water-intensive cropping patterns than the currently predominant winter wheat/summer maize combination is one suggestion. The amount of water saved will depend on the length of the growing season, the root depth and the leaf area. Studies have shown, however, that any cropping routine which includes a winter wheat cycle will not show any significant reduction in groundwater depletion (fig. 8). It would appear then that the reintroduction of a winter fallow season is the only way of seeing any significant water savings through crop changes. This, unfortunately, is not an option which, by and large, is likely to be socially and economically palatable.

Figure 8. Estimated groundwater declines that would have resulted from five different summer and winter crop combinations under typical irrigation practices, given historical climate conditions in Luancheng Country, 1962-2000



Source: Kendy et al. 2003b.

Another option is the transformation of land use from rural to urban. While specific data is not available for the Luancheng County, it is commonly accepted that urban land use depletes much less water than crop evapotranspiration. An urban setting would call for a different range of water conservation measures. In the city of Shijiazhuang, overpumping of groundwater has resulted in the deformation of the water table into a funnel shape. This has affected elevations of water levels at different points and has caused directional changes to the natural flow of groundwater. Thus water that would naturally have flowed to the aquifers of Luancheng County is flowing instead to the aquifers of Shijiazhuang city. It is imperative that the net amount of water pumped for the city is reduced if this unsustainable situation is to be reversed.

In an urban setting, precipitation tends to leave the system as runoff, rather than recharging the underlying aquifer, since many of the land surfaces are impermeable. Here, unlike in the study area, efficiency technologies would have a significant effect. A more expensive option is that wastewater is treated and then used to recharge the aquifer. Studies in California have shown that both these measures, though expensive, show better results in terms of water yield-to-cost ratios than agricultural water conservation, land fallowing and surface storage construction.

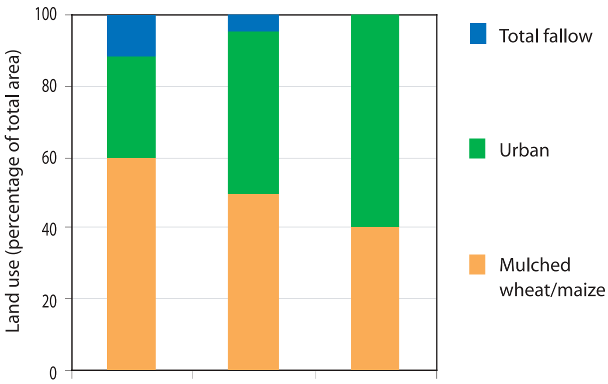
With respect to improving urban water use efficiency industrial facilities provide greater potential savings than do households. Water use per industrial product in China is 3 to 10 times greater than in other industrialized countries. Discouraging water-intensive industries is a measure that has been adopted in some Chinese cities. Likewise there are many different measures that can be considered singly or together in the urban context to provide optimal water use efficiency.

Making the right choice…

None of the measures described earlier will be sufficient on their own to solve the problem of groundwater depletion. Thus, an appropriate mix of measures must be identified to achieve optimal water savings and reduced levels of groundwater depletion.

Using the kind of thinking underlying the concept of hydronomic zoning, together with a water balance approach, the study in Luancheng County set out to identify the right mixture of solutions. It formulated water saving choices which could be adopted. The sets of options are made up of a combination of changing cropping patterns, leaving certain areas of land to lie fallow, and change of land use to urban uses. Each set of options is calculated to deplete only 460 mm/yr—bringing the rainfall and evapotranspiration into equilibrium (fig. 9).

Figure 9. Examples of land-uses which, combined, deplete approximately 460 mm/year of water—under the assumption that all wheat and maize is either mulched or replaced with vegetable crops, thereby reducing evapotranspiration by 100 mm/year



Note: Each stacked bar represents a different combination of land use: total fallow, urban and irrigated agriculture.

This analysis leads to the conclusion that withdrawing some land from irrigation is an inevitable part of the solution to achieving sustainable water use in the North China Plain. This change in land use will be flying in the face of the longstanding policy of food self sufficiency and use of groundwater to meet this goal. Thus, incentives which are socially, politically and economically acceptable will need to be offered to bring about this change.

In the final analysis, it is clear that simplistic 'one size fits all' solutions will not always be effective in saving water. A holistic approach including techniques such as a water balance approach and hydronomic zoning is necessary to identify the most effective methods of halting and reversing rates of groundwater decline.

Drilling new irrigation well on the North China Plain.

Water Policy Briefing Series

The ***Water Policy Briefing*** Series translates peer-reviewed research findings into useful information for policymakers and planners. It is published several times yearly, with the goal of bringing new and practical approaches to water management and planning into the policy recommendation process. The series is put out by the International Water Management Institute (IWMI) in collaboration with national and international research organizations. It is free of charge to development professionals.

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Theme 2: Land , Water and Livelihoods: *improving livelihoods for the rural poor*
Theme 3: Agriculture, Water and Cities: *making an asset out of wastewater*
Theme 4: Water Management and Environment: *balancing water for food and nature*

The Institute concentrates on water and related land management challenges faced by poor rural communities in Africa and Asia. The challenges are those that affect their nutrition, income and health, as well as the integrity of environmental services on which food and livelihood security depends. IWMI works through collaborative research with partners in the North and South, to develop tools and practices to help developing countries eradicate poverty and better manage their water and land resources. The immediate target groups of IWMI's research include the scientific community, policy makers, project implementers and individual farmers.

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