ACHIEVING GROUNDWATER USE EFFICIENCY IN NORTHERN CHINA

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EXECUTIVE SUMMARY

Major groundwater development in the North China Plain has been a key factor in the huge economic growth of China and the achievement of self sufficiency in food production. This has however produced major and continuing groundwater level decline and many associated problems: hundreds of thousands of dry wells, sea water intrusion, land subsidence over vast areas and groundwater salinisation. Groundwater levels in the shallow unconfined aquifers have fallen from 10m up to 50m, at an average rate of 0.5m/year. In the deep confined aquifers levels have commonly fallen 30m and up to 90m, at an average rate of 3 to 5m/year. This is a potentially disastrous problem, as at the current rate of extraction the groundwater resource will only last for several decades more.

A broad range of strategies have been developed through several World Bank and Peoples Republic of China (PRP) projects. In relation to groundwater management, both supply side and demand side measures have been evaluated. Demand side measures, principally more efficient irrigation leading to "real water savings", is considered to be the only realistic option. The effectiveness of achieving real water savings leading to reduced groundwater extraction is beginning to be demonstrated in several "pilot" counties. Engineering, agronomic and planning measures are required to achieve real water savings. The broad scale adoption of this strategy will be dependent upon comprehensive water management at both national ("top down") and local ("bottom up") scales. The roles of the many levels of water managers need to be redefined and focussed to achieve "real water savings" without a major reduction in agricultural production. The strategy has many components, including the defining of groundwater management areas and associated target yields ("sustainable" yields), an improved licensing and allocation system, institutional reforms, programs to address groundwater pollution, metering and monitoring, price increases and community education. The implementation of the total strategy will require a huge effort.

INTRODUCTION

Major groundwater development in the North China Plain, which commenced in the 1960s, has been a key factor in the huge economic growth of China and the achievement of self sufficiency in food production. This irrigation based development has been focussed in three catchments the Hai, Huai and Huang (Yellow) river basins, the 3H basins. The 3H basins represent the "bread basket" of China, where 430 million people live. The continued growth in population and industry has resulted in a severe freshwater shortage and massive pollution. The growing demand for water resulted in the rapid growth in groundwater usage from the 1960s. This in turn has led to massive falls in groundwater levels and associated environmental problems. To address these issues a Groundwater Management Strategy for the North China Plain is being formulated. This paper describes the groundwater resources of the 3H basins, their associated issues and describes the development of the management strategy.

This strategy is aimed at achieving a significant increase in irrigation water use efficiency in northern China. The current practices are completely unsustainable and unless a radical change in water use is achieved there will be major water shortages in only several decades over a huge area with a very high population. The strategy recognises that although technically focussed options are the primary goal, the effective implementation and adoption of those options is strongly influenced by social and institutional factors.

This work has been predominantly funded by the World Bank with assistance from the Ministry for Water Resources, PRC, AusAid and other funding partners. The World Bank (2001) presents much of the background data.

HYDROGEOLOGY OF THE NORTH CHINA PLAIN

The 3H basins are in northern China, as shown in Figure 1. The rainfall in northern China is much less than in southern China (see Figure 2), with a typical rainfall in the North China Plain of about 500mm. The surface runoff and estimated groundwater exploitable yield of the nine major basins in China is shown in Table 1.

Table1: Groundwater exploitable yield, surface runoff and their ratios for the major basins of China (Billions of cubic meters per year)

Basins	Surface Runoff	Groundwater	Ratio G/S)
Hai River	28.8	26.5	0.92
Huang River	66.2	40.6	0.61
Huai Rivr	74.1	39.3	0.53
Inland River	116.4	86.2	0.74
Songliao	165.0	62.5	0.38
Yangtze	951.3	246.4	0.26
Southwest China	585.3	154.4	0.26
South China	468.5	111.6	0.24
Southeast China	255.7	61.3	0.24
Total	2712.0	829.0	0.31

Data Source: Wu Yiao, et al. (1986)

It is noted that the 3H basins have moderate sized groundwater resources in comparison with the rest of China. However if the same data is compared with available surface water resources, then in proportion the groundwater resources of the 3H basins are a much more important component of the total available water resource.

Considering the 3H basins, the groundwater resources can be divided into two major hydrogeological units – the mountains and the plains. The mountains contain relatively less resources than the plains. The mountains groundwater resources are generally in fractured rock and karst (limestone) formations. The plains consist of Quaternary alluvial sediments up to almost 1000m in thickness. This semi-arid area of north-eastern China (termed here the North China Plain) comprises three main hydrogeologcal settings (Evans & Han, 1999) (Figure 3):

- the gently-sloping piedmont plain and associated major alluvial fans of the principal rivers,
- the main alluvial plain (Heilongang), with many abandoned channels of the Hai River its tributaries, the Lower Huai River and the Lower Huang (Yellow) River,
- the coastal plain strip around the margin of the Bohai Sea.

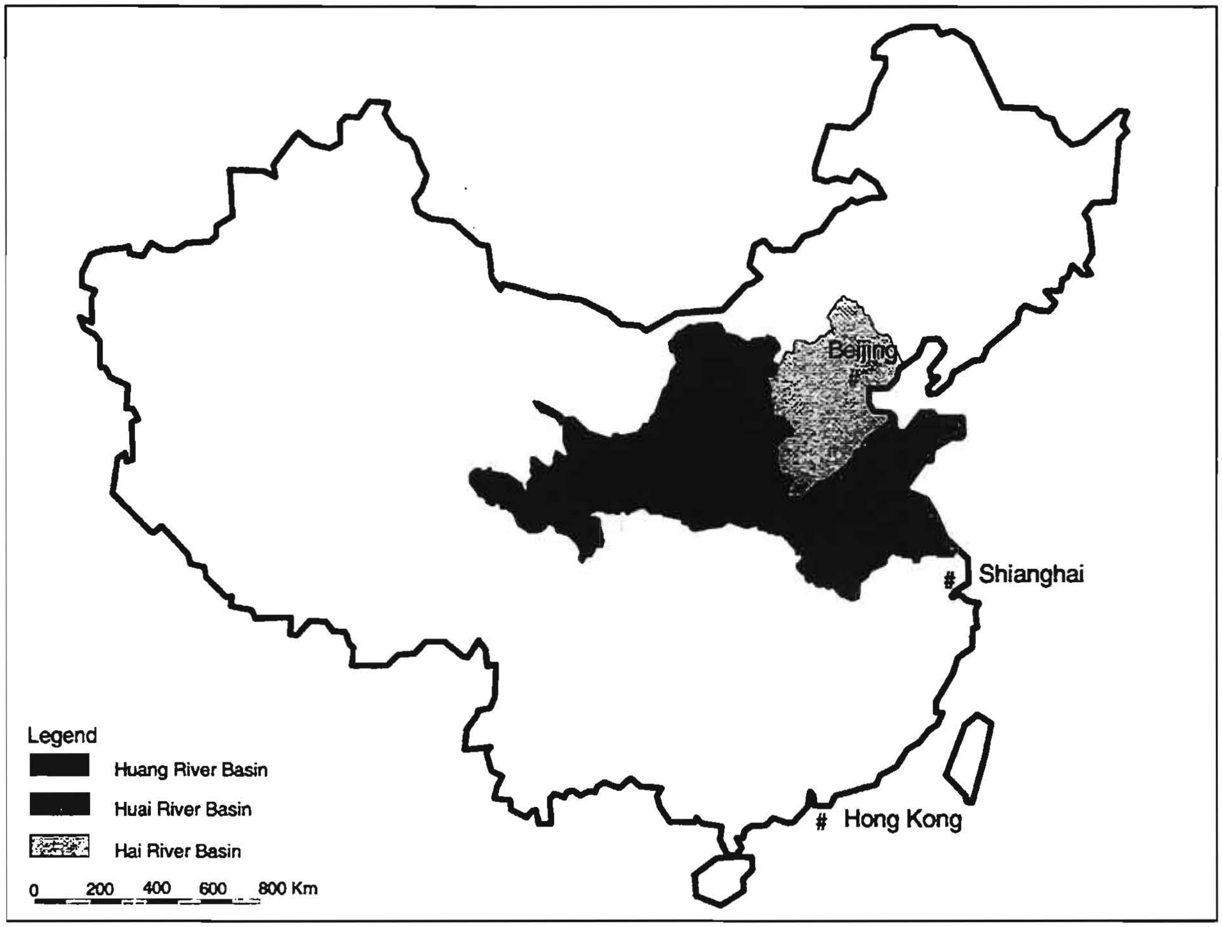

Figure 1: Location of 3H Basins in China

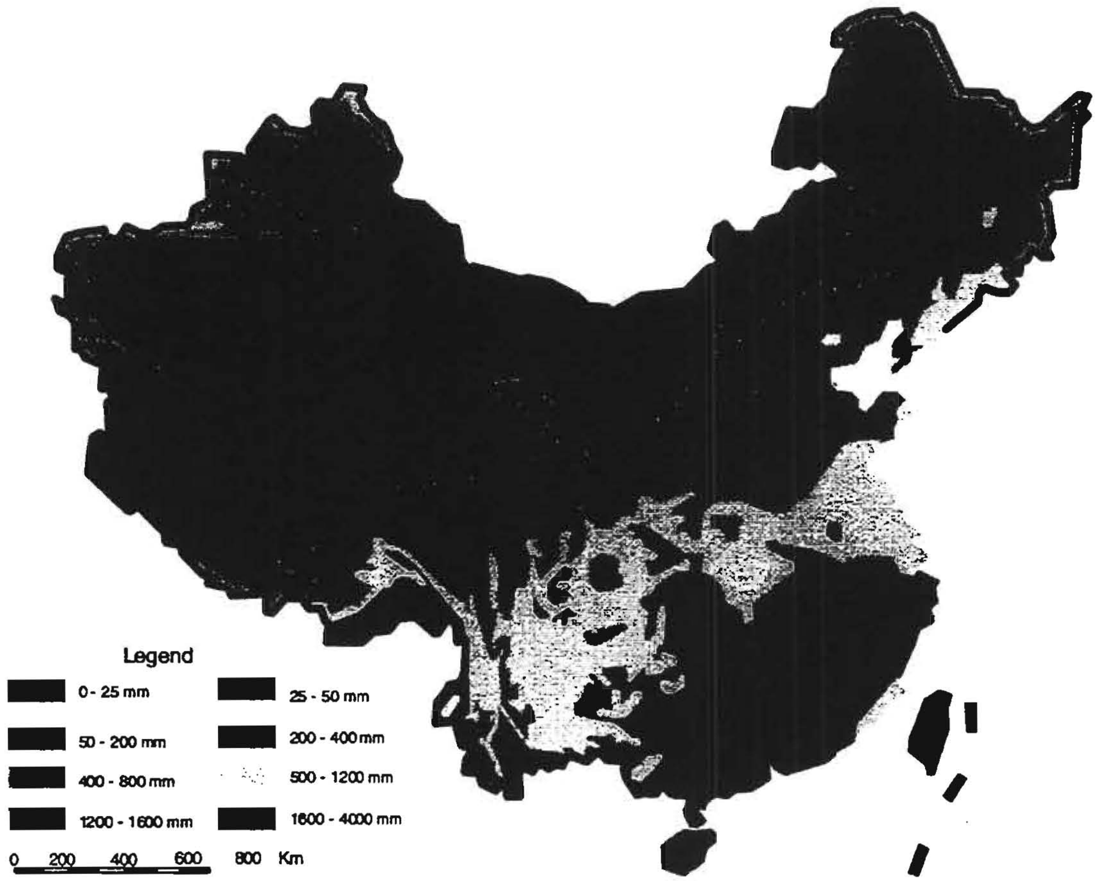

Figure 2: Mean Annual Precipitation in China from 1956 to 1979

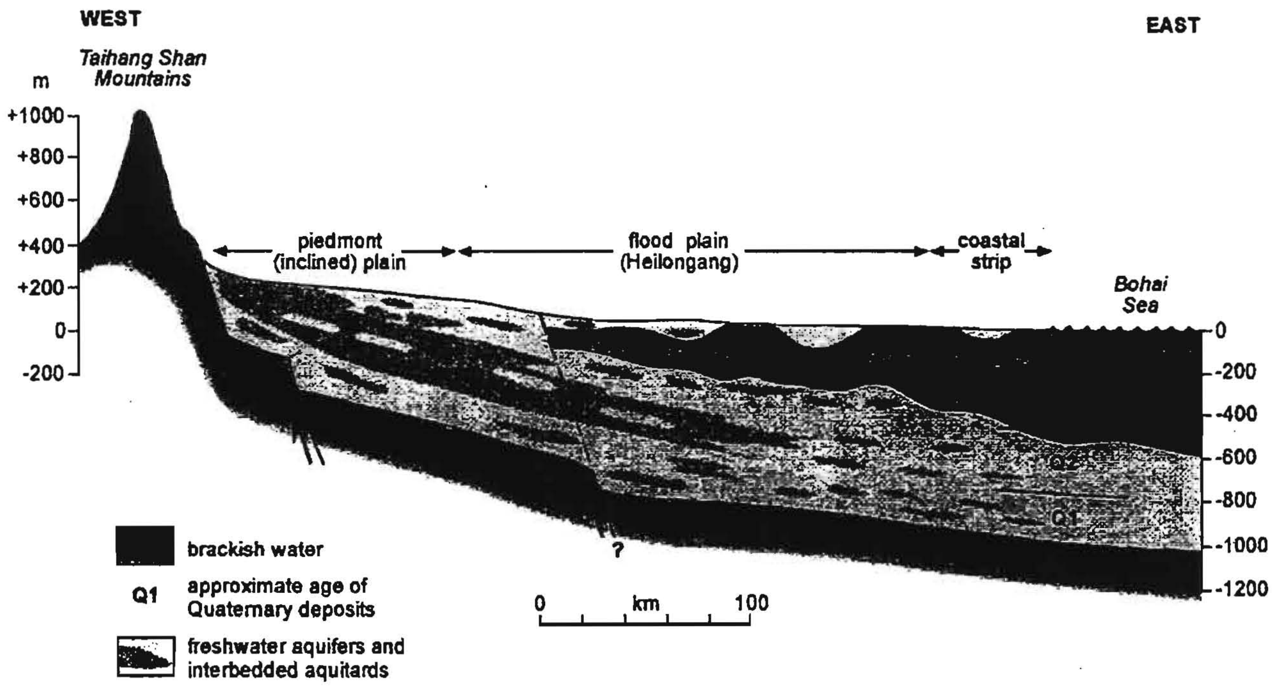

Figure 3: Diagrammatic Cross Section of Quaternary Aquifers in North China Plain

Four major Quaternary aquifers are identified. The western edge of the plain, at the edge of Taihang Mountains, contains coarse sediments. The saline groundwater region (with typical salinities greater than 2g/L) is indicated in the upper aquifers, whereas the deeper confined Q_1 and Q_2 aquifers tend to have better quality groundwater.

The Quaternary alluvial aquifers across the North China plain represent a shallow unconfined aquifer (Q_4) which is recharged vertically by rainfall, and a series of deeper confined aquifers (Q_1, Q_2 and Q_3). The alluvial fan at the foot of the mountains consists of coarser sediments.

The recharge to the deeper confined aquifers is notionally by horizontal through flow from the recharge areas at the basin margin on the west, and by vertical leakage from overlying aquifers. However the rate of horizontal flow is very slow and vertical leakage is often small, and hence much of the groundwater in the deep confined aquifers can be considered to represent "fossil" water with limited recharge.

GROUNDWATER USE IN THE 3H BASINS

The estimated groundwater use in the 3H basins for 1997 is shown in Table 2.

Table 2: Groundwater use in 3-H basins (1997)
(Billions of cubic meters per year)

River Basin	Shallow	Deep	Total
Hai Basin	20.9	6.4	27.3
Huai Basin	14.2	4.2	18.4
Huang Basin	9.8	4.0	13.8
Total	44.9	14.7	59.6

This data is broken up between the shallow unconfined aquifer and the deeper confined aquifers. Approximately 25% of all groundwater used is from the deep aquifers. The water use from groundwater and surface water in the 3-H basins is, for 1997, as follows:

Table 3: Surface water and groundwater use in 3-H basins in 1997
(Billions of cubic meters per year)

River Basin	Surface Water	Groundwater	Total
Hai Basin	16.1	27.3	43.7
Huai Basin	55.4	18.4	74.2
Huang Basin	27.7	13.8	41.8
Total	99.4	59.6	159.7

Groundwater use is very important in all three basins, but especially important in the Hai River Basin. In terms of total water use in all of China, groundwater plays a much more important role in northern China than in southern China. Groundwater use in the 3H basins for urban supply purposes is mostly from the deep confined aquifers although actual data is not available.

A comparison between the amount of groundwater available (the exploitable fresh groundwater) and the groundwater use in 1997 is provided in Table 4. Even though on average over all of the 3H basins, the use is almost equal to the available groundwater resource, this is misleading. All of the Hai River Basin is over-exploited and some areas of the Huai and Huang are over-exploited. If data were available at a smaller scale the extent of over-development would be much more extreme. Furthermore, even though in a particular area the use may not appear to be excessive, if the exploitable yield from the deep aquifers especially were compared with usage, then the extent of over-exploitation would be even greater in some areas.

Table 4: Groundwater resources and use in 3H areas
(Billions of cubic meters per year)

River Basin	Exploitable Fresh Groundwater	Use of Groundwater in 1997	Use/Exploitable
Hai Basin	17.3	27.4	1.58
Haai Basin	24.0	18.4	0.77
Huang Basin	18.2	13.8	0.76
Total	59.5	59.6	1.003

GROUNDWATER ISSUES

Resource Over-Exploitation

Few regions in the world would have such vast areas of over-exploited groundwater resources. The large scale dropping in water table level in the shallow unconfined aquifers and pressure levels in the deeper confined aquifers not only causes many hundreds of thousands of bores to go dry but also cause many other environmental problems.

Crook et al. (1999) provide a graphic account of the immense scale of the drawdown cones which cover an area greater than 80,000km^2. Based on the rate of decline from 1980 to 1996, the entire western side of the North China Plain will be depleted by 2030. Associated with this massive overdraft will be very damaging land subsidence. Parts of Beijing have already subsided over 1 metre with far greater subsidence elsewhere. A draft report (June 2000) by the Hai River Basin River Resources Committee concludes that the groundwater resources of the Hai River Basin are 130% over-exploited, with the shallow and deep aquifers being 113% and 238% respectively over-exploited. These figures represent the average over a very large area and disguise the fact that in may local areas the extent of over-development is far greater. From 1958 to 1998 deep groundwater levels have fallen up to 90m and commonly 60m over a huge area of the North China Plain. Figure 4 from Hai River Basin Committee (2000), show the change in shallow groundwater level in the Hai Basin Plain from 1958 to 1998.

In Hebei Province, the shallow water table level has dropped 5m, to 12m depth, from 1983 to 1999 over large areas. The average rate of water table decline is 0.4m/year. Over 8000km^2 the water table has dropped 8m at a rate of up to 1.2m/year to 25m below the surface. The deep aquifer pressures have dropped up to 10m below sea level in some areas. The rate of water level decline from 1990 to 1995 was 1m/year.

Pollution

Unpolluted groundwater is usually of better quality than surface water, especially from the deep confined aquifers. The deep aquifers commonly have a concentration of total dissolved salts of less than 1g/L. The typical quality of the shallow unconfined groundwater across the North China plain often has a concentration exceeding 1g/L.

Extensive areas of China have considerable groundwater pollution. The shallow unconfined aquifer, and in some cases the deep confined aquifers, are extensively polluted. The major pollution sources are primarily wastewater discharges from the cities and towns, which are used for irrigation, and also include pesticides, nutrients and heavy metals.

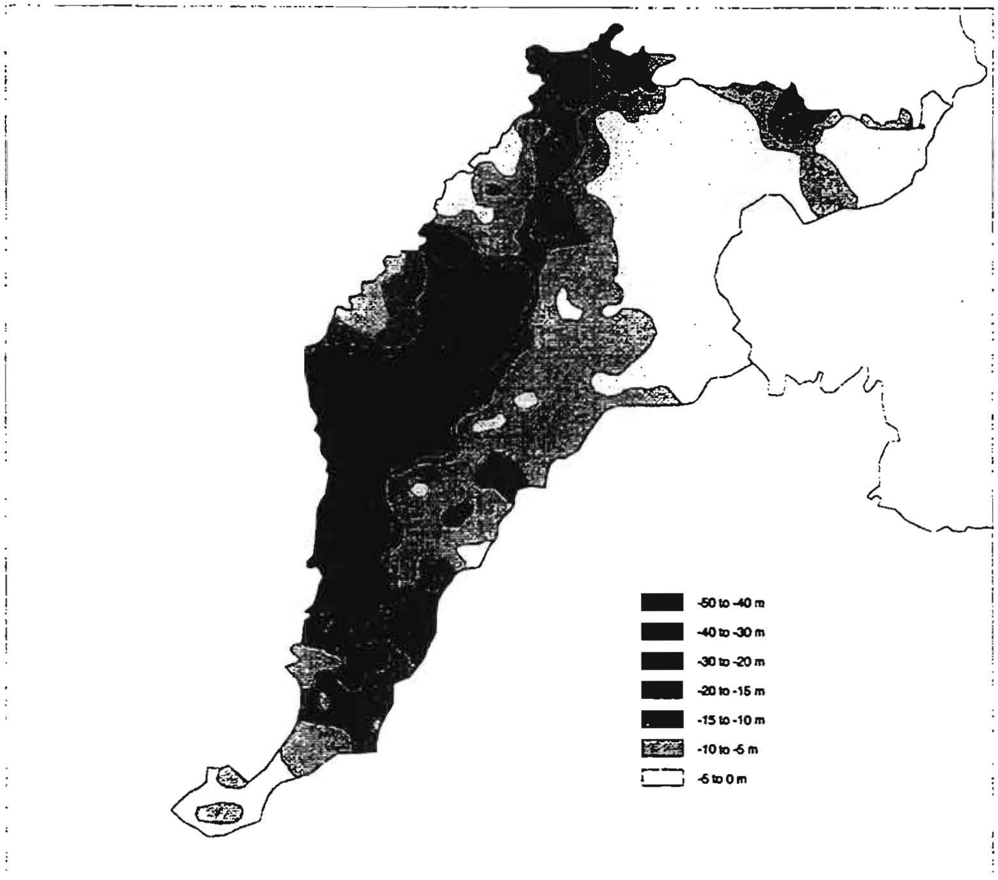

Figure 4: Changes in Shallow Groundwater Level in Hai Basin Plain from 1958 to 1998

Limited groundwater quality monitoring exists in China and this is principally focussed near cities. Hence no province wide (nor nation wide) assessment is available. The extent of pollution in rural areas is not at all well understood, nor monitored.

A largely naturally occurring groundwater quality problem in China is fluoride. There are large areas in northern China, and especially in the 3-H basins, where the fluoride level is causing major health problems. According to Tang (1998) in Tianjin city and Cangzhou city of Hebei province, about four million people are suffering fluoride induced heath problems, including teeth disease. Arsenic pollution of the groundwater, due to the release of arsenic as water tables are lowered, is also a major problem in many areas. The arsenic content is generally 0.05 to 1.2mg/L but at times it exceeds 2mg/L.

Quality Degradation

Quality degradation is completely different from pollution in the sense that pollution refers to the introduction of external pollutants into aquifers, whereas quality degradation refers to the migration of poorer quality groundwater into good quality aquifers as a result of the decrease in pressure/water level within the exploited aquifer. Strictly speaking, sea water intrusion is a special case of quality degradation. This will be discussed in the following section. A diagrammatic cross section of possible salinity degradation mechanisms is shown in Figure 5.

Frequently the shallow unconfined aquifer is saline and the aquifers to the south east are more saline. Hence when, for example as in Figure 5, extraction occurs from the intermediate depth confined aquifer, there is both horizontal and vertical migration of saline water into the good quality aquifer being pumped. The relative significance of horizontal to vertical leakage is very important from the point of view of developing management strategies, especially artificial recharge, to counter this aquifer salinisation mechanism. It is believed that vertical leakage is far more important than horizontal migration.

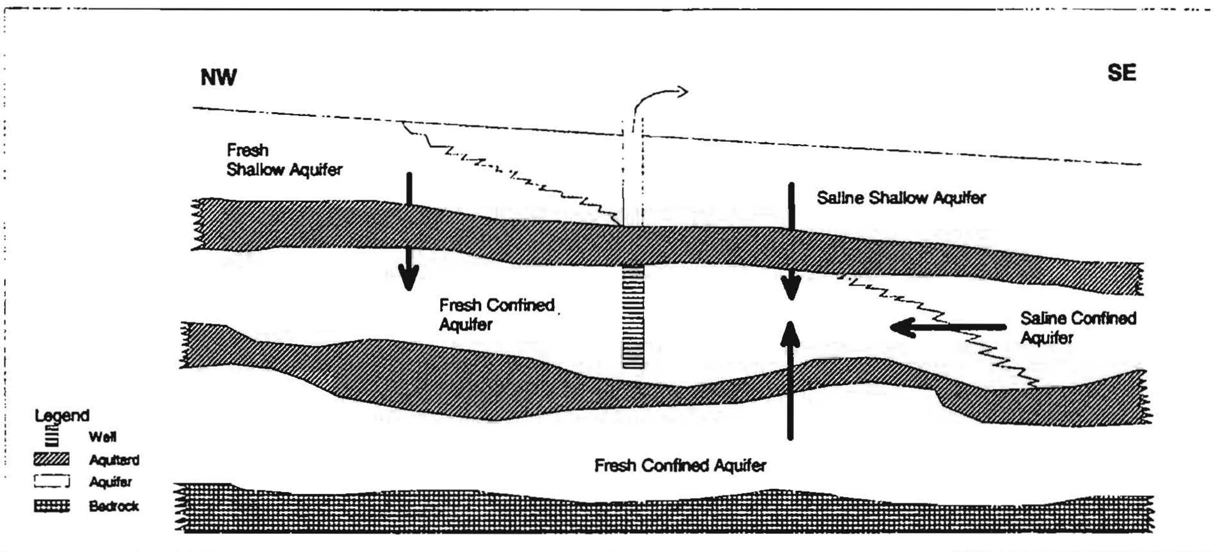

Figure 5: Diagrammatic Cross Section of Possible Salinity Degradation Mechanisms in the North China Plain

Sea Water Intrusion

Sea water intrusion occurs in many coastal regions of China where the coastal groundwater resources are over- exploited. According to Tang (1998) there are up to 72 areas where sea water intrusion has occurred in Hebei, Shandong and Liaoning provinces, covering an area of 1434km^2 in 1992. In the coastal areas of these provinces, the groundwater level is below seawater level over an area of 2000km^2 and is expanding. Sea water intrusion has reportedly caused 8000 wells to be abandoned, resulting in over one million people having problems accessing drinking water.

Subsidence

There are many reported cases of land subsidence in China resulting from groundwater resource over-exploitation, of which most are due to extraction from deep confined aquifers. Considering the plains area of Hebei province, the total area of land subsidence (Zhang, 1998) greater than 100mm has exceeded 33900km^2, accounting for 55% of the total land area. In south Beijing and Tianjin Municipalities by 1994, subsidence reached 1.523m, with an average rate from 1991 to 1994 of 48mm/year. This has caused settlement of structures, bridges to collapse, significantly aggravated stormwater drainage problems, and a reduction in the capacity of the river levees to resist high tides and floods. No accurate cost estimates of the damage are available, however since 1985 the cost has been approximately estimated at 1.385 billion yuan. A similar story is repeated in many other key cities throughout the 3H basins, including Taiyuan and Shijiazhuang.

In Shanghai, major groundwater usage from 1921 to 1986 resulted in a water table drawdown of 35m and resulting subsidence of 2.63m. The introduction of an artificial recharge scheme has largely controlled the subsidence. In other locations, ongoing subsidence over large areas has only been controlled by reducing extractions. Still there are many areas, mostly associated with urban groundwater use, where serious subsidence is continuing.

Overview

The groundwater problems described above do not occur as individual issues. They are frequently interrelated. The ongoing drawdown in groundwater levels results in reduced yields of wells, sharp increases in operating costs, frequent need for replacement of pumping facilities, and the abandoning of wells. Subsidence, salinity degradation, migration of polluted groundwater into good quality aquifers, and sea water intrusion (for coastal areas) are all consequential problems of over-exploitation.

OPTIONS TO ADDRESS OVER-DEVELOPED GROUNDWATER RESOURCES

The massive scale over development in the 3H Basins is clearly unsustainable and urgent action is required, otherwise a massive scale predictable human tragedy will occur in several decades. With a problem of this scale, multiple strategies are required to reduce groundwater use to sustainable levels.. The World Bank (2001) strategy deals with many other broader strategies to bring overall water usage into a sustainable framework. In brief, these other strategies include:

- South to North Grain Transfer, with the aim of reducing the demand for groundwater irrigated wheat
- South to North Water Transfer – this massive engineering project would mainly focus on urban water demand
- Crop changes – to reduce irrigated wheat especially
- Industrial water savings
- Urban water savings
- Use of wastewater (including artificial recharge)
- Use of brackish/saline groundwater

In addition, the feasibility of large scale artificial groundwater recharge has also been considered. Although clearly having a major role in some regions, the scale of the groundwater over development problem could never be solved by artificial recharge because of the lack of surface water or wastewater for artificial recharge.

The volume of groundwater being extracted must be reduced by a combination of:

- Substitution with wastewater
- Inter basin transfers

- More efficient irrigation practices

The last option – more efficient irrigation – is seen as the primary option. The feasibility of achieving more efficient irrigation is the primary aim of this paper. Historically, in China and in many other regions of the world the solution to over-developed groundwater problems has been the introduction of "supply side measures". These include artificial aquifer recharge, water harvesting and water transfers. However, it is believed that "demand side measures" are needed in China and will make a far bigger contribution to solving the problems. These demand measures include real water savings in agricultural irrigation, agricultural cropping changes and bans on cereal irrigation. Across the North China Plain, the applicability and effectiveness of the two alternative strategies will vary with the hydrogeological settings. Nonetheless, enthusiasm for water demand management must be promoted. As approximately 70% of groundwater is used for irrigation, reducing irrigation usage must be the principal strategy.

ACHIEVING AGRICULTURAL WATER USE EFFICIENCY

The massive scale groundwater development has been estimated at representing an average recharge deficit of 40 to 90 mm/a. Independent assessment of crop demand water deficit varies from 80 to 140 mm/annum for irrigated wheat and maize. Hence the agricultural water demand is in the same order as the groundwater over-development. Obviously, any broad scale average disguises significant local variations.

There is much evidence (for example, Shen and Wang 1999) that agricultural water saving measures can reduce non-beneficial evapotranspiration (NBET). It is estimated that for the most important crops the water use can be reduced by up to 50 and 80mm/a/crop for groundwater and surface water irrigation respectively. The difference is because groundwater irrigation is intrinsically more efficient than surface water irrigation as a consequence of temporal availability, smaller irrigation command area and higher energy costs usually associated with groundwater. The agricultural water saving measures are:

- engineering measures: such as irrigation water distribution through low-pressure pipes (instead of open earth canals) and irrigation application through drip and micro-sprinkler technology
- management measures: to improve irrigation forecasting, water scheduling and soil moisture management
- agronomic measures: such as deep ploughing, straw and plastic mulching and the use of improved strains/seeds and drought-resistant agents

Such measures are considered capable of reducing the rate of decline in the deep confined aquifer and of making a contribution to the stabilisation of the watertable of the shallow aquifer. These measures are shown diagrammatically in Figure 6.

One of the major measures being introduced is the use of plastic to reduce NBET. This can be in the form of green houses, as shown in Figure 7, or directly applied to the ground surface, as in Figure 8. The adoption of these technologies is relatively recent, but is now being applied over large areas of the North China Plain. The use of plastic in this manner and other technologies represents relatively radical changes in land use and crop types. This is generally only feasible where markets exist for these new crops and transport and storage facilities exist. Currently this is only feasible close to major urban centres.

It must be emphasised that "real water savings" (RWS) is not "irrigation efficiency" (IE). Irrigation efficiency includes several concepts - irrigation water application efficiency, irrigation water delivery efficiency and irrigation water storage efficiency. Because "real water savings" specifically considers NBET and allows for groundwater recharge as being a positive contribution to the total water cycle, hence RWS is a different concept from IE.

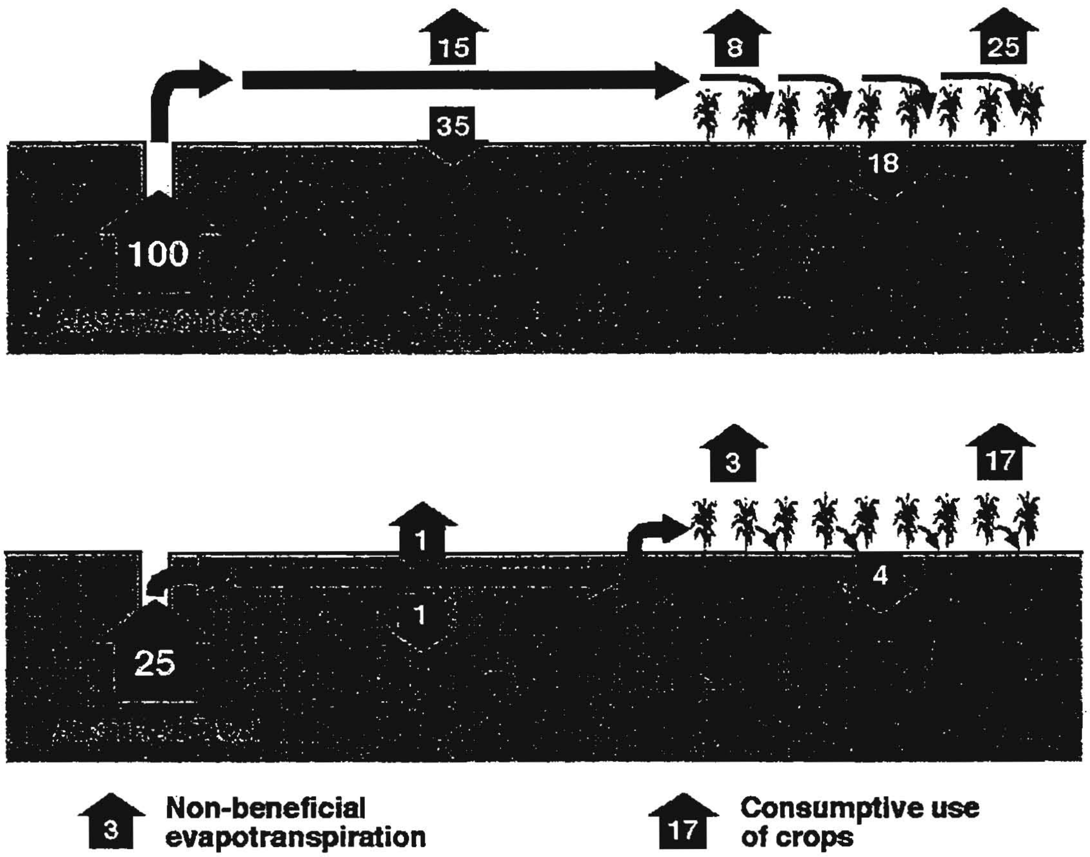

Figure 6: Concept of Improved Irrigation Methods Producing Real Water Savings

Figure 7: Greenhouse Cultivation

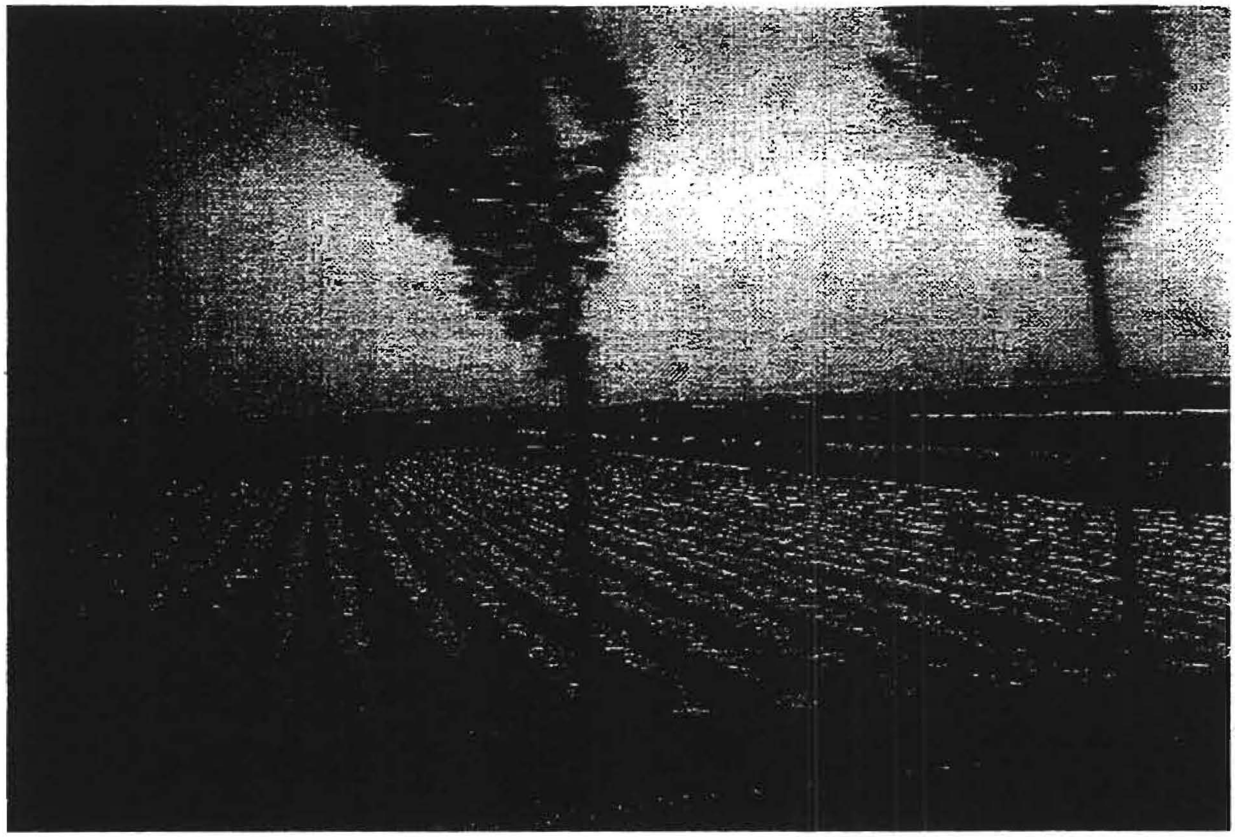

Figure 8: Use of Plastic to Reduce NBET

GROUNDWATER MANAGEMENT PLANNING

Overall Strategy

The achievement of real water savings is heavily dependent upon water-user participation and ownership. The ability of the agricultural water saving measures to reduce, and even halt, the declines in groundwater levels must be directly related to permanent reductions in groundwater extraction. Experience in other parts of the world suggests that agricultural water savings may be simply transferred to expanded irrigation elsewhere or increase groundwater use in other sectors. To ensure that this does not occur and to provide a long term strategic framework, it is proposed that groundwater management in China must involve both "top down" National scale strategic objectives and planning combined with "bottom up" local scale practical management measures. It is essential that these two different approaches "meet" to provide a coherent message to ground water users. It must be noted that effective groundwater management is fundamentally different from surface water management, in the sense that groundwater users are usually scattered throughout a region, while surface water users are usually in clearly defined irrigation districts and/or close to rivers. The "diffuse" nature of groundwater users calls for much greater community education and ownership for effective management to be introduced.

The approach beginning to be applied in the North China Plain is as follows:

Current Groundwater Management Arrangements

At the National level the Ministry for Water Resources (MWR) provides overall water policy and planning direction. The relatively nearly established River Basin Commissions (for the 3H basins) to date have had little input to groundwater management. The Provincial (and Municipal) Water Resource Business (PWRB) have tended to provide province scale policy directions. Most practical management occurs through the Country (and District) Water Resource Bureau's (CWRB). This decentralised approach provides for a close link between managers and users. Recently the users input has been more formally recognised with the establishment of Water Users Association

(WUAs), which typically might represent a relatively small area of about 10% of a county. The WUAs provide a good model for achieving active user participation.

Although rapidly changing at the moment, there are nonetheless some significant historical factors which retard effective groundwater management in many counties:

- slow rate of licensing of many extraction bores, even though licensing commenced in 1993
- no linkage exists between licensed extraction rates and groundwater resource availability; there is little linkage between technical (including researchers and universities) and administrative personnel
- WUAs generally only represent irrigators and other users (eg, urban, industrial) are not represented
- a comprehensive water rights system (Garduno 2001) is lacking, which makes water saving enforcement difficult
- there is little integration of surface water, groundwater and wastewater management
- data is not shared between relevant authorities
- there is no mechanism to deal with inter-county groundwater interaction; even though groundwater management is best undertaken at the county level, the scale of the groundwater drawdown is for larger and hence the good actions of one county can be undermined by the inaction of adjacent counties
- little groundwater level monitoring data exists

These problems are gradually being addressed, although the huge size of problems on the North China Plain calls for more serious National focus on effective management. This is beginning to be achieved as follows:

"Top Down" Approach

"Top Down" refers to the centrally planned overall framework undertaken at the National, River Basin and Provincial scales.

The development of a process for groundwater management planning in China must incorporate four components:

- a rigorous technical foundation
- a strong legal/policy environment
- effective institutional arrangements
- a comprehensive management framework

The first three components must be comprehensively addressed to enable the last component to operate. The overall objective of the strategy is to reduce groundwater usage in the 3H Basins to sustainable levels by 2015.

The National Groundwater Management Strategy is structured around defining sensible Groundwater Resource Management Areas (GWRMAs). The River Basins, Provinces and Counties are generally not hydrogeologically sensible management areas.

In most cases, the GWRMA will cover one aquifer only. There can be multiple GWRMAs overlying each other if there are multiple aquifers that behave essentially independently. For the Hai river basin, some 10 to 100 GWRMAs would be identified.

The first step also requires the definition of a target yield for each GWRMA. The so called target yields are ideally based on a sustainable yield concept although in some circumstances the target may not necessarily be sustainable. "Sustainability" implies use of a resource in such a way that does not preclude the same level of use for future generations. However, because groundwater has been over exploited for several decades, it is impossible to return to earlier levels of access. Hence, the aim of the groundwater management plans is to stop further over exploitation and control pollution to prevent loss of groundwater quality.

A specific groundwater management plan is to be devised for each GWRMA to take into account the local groundwater problems and needs of the community in line with national groundwater management principles. Then the GWRMAs should be prioritised based on the ratio of current usage to target yield (TY). For example, GWRMAs with usage per TY ratio > 1.5 should be classified as heavily over exploited, and their groundwater management plans should be implemented as matters of urgency.

These steps are summarised as follows:

1. Define Groundwater Resource Management Areas (GRWMA) in 3H Basins

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2. Determine Target Yield for every GWRMA

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3. Identify Level of Allocation and estimate Usage for every GRWMA

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4. Categorise Every GRWMA
   4 = Use < 70 percent TY
   3 = Use 70 to 100 percent TY
   2 = Use 100 to 150 percent TY
   1 = Use > 150 percent TY

↓

5. Prioritise Every GWRMA for example, Category 1 GRWMA to have GMPs by 2004

"Bottom Up" Approach

The "Bottom Up" approach refers to the local scale (at Council, District and township levels) day to day licensing, regulation and monitoring. In practice, this means both effective local management and active groundwater user input. The recent establishment of Water User Associations (WUAs) has been a significant new initiative. In addition, metering of groundwater extractions has commenced, although considering the size of the task it will take many years to fully implement. To achieve effective local management various institutional and social issues are gradually being addressed:

- the concept of "real water savings" needs to be grasped by improved education

- extraction (volume) targets for WUA must be set; these will generally be a subset of the target volumes set for the GRWMAs
- closer linkages are required between agricultural extension services (promoting water savings) and groundwater extraction licensing
- increasing water resource fees for abstraction
- increased groundwater level monitoring
- introduction of more efficient irrigation technology
- support for WUAs and greater emphasis on defining roles at all levels of groundwater management

Integration

The massive size of the problem to be addressed requires strong integration of management activities. The action of individual CWRBs will not be sufficient to stabilise groundwater levels. To ensure that local actions are effective they need to be co-ordinated with provincial and even national level actions and policies. These are presented diagrammatically in Figure 9. The required integration includes consideration of:

- the target yields for the GWRMAs need to be set in consultation with the PWRBs and then related to the groundwater extraction licences issued by the PWRBs
- the MWR role, in addition to overall policy and national scale planning is also to facilitate and monitor the actions of the PWRBs
- substantial capacity building programs need to be implemented

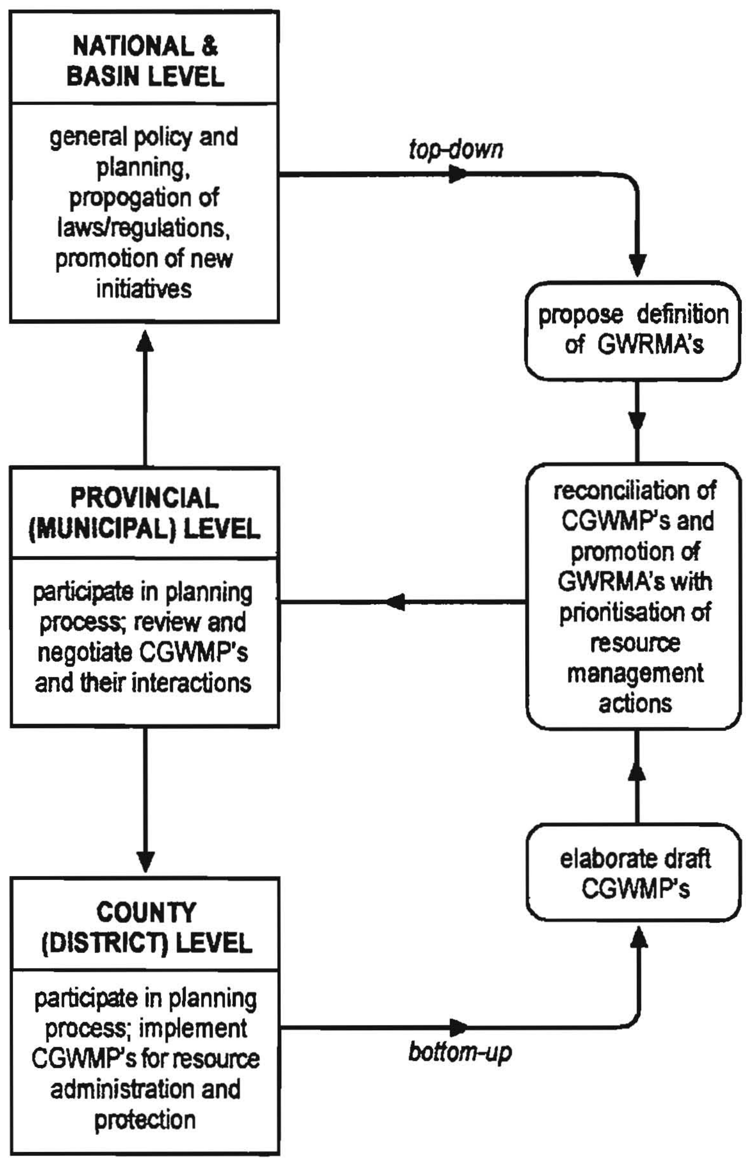

Figure 9: Groundwater Management Planning Process

CONCLUSIONS

To achieve the objective of reducing groundwater usage to sustainable levels by 2015 will require a fundamental paradigm shift. The basic concept of sustainability will need to be understood and accepted by all stakeholders. This is beginning to occur. The implications of not reaching this aim are huge. For example, reduced groundwater levels to the extent that virtually all existing bores would be dry, significantly reduced yields in most areas and no groundwater in many areas, massive land subsidence, sea water intrusion and water quality degradation on a scale which would be virtually irreversible. Groundwater in many areas can act as an insurance water supply in times of drought. If the current groundwater trends continue, future generations will have lost this insurance.

It is believed that more efficient irrigation to produce "real water savings" is an effective strategy which can result in reduced groundwater usage to an extent sufficient to stabilise groundwater levels.

The "top down" and "bottom up" management approaches provide a framework for fundamental institutional change which is needed to achieve this fundamentally important goal. This is now beginning to occur in several "pilot" counties where impressive management reforms are being introduced. But the size of the problem is so great that long term fundamental change, at all levels of water management, is needed to achieve the goal.

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ACKNOWLEDGEMENT

Much of this paper is based upon a soon to be published paper by S Foster, H Garduno and R Evans as part of the World Bank – Global Water Partnership.

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