

Sustainable Groundwater Management Lessons from Practice

Case Profile Collection Number 8

Towards Sustainable Groundwater Resource Use for Irrigated Agriculture on the North China Plain

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GW•MATE is providing assistance to the major World Bank-funded MWR Water Conservation Project, the aim of which is to promote 'real water-savings' in irrigated agriculture and thus reduce the current overdraft of groundwater reserves on the North China Plain. Groundwater management efforts are focused in county-level pilot projects. Guantao County is one such pilot project, representative of areas using both the shallow and deep freshwater aquifers, and the GCWRB is acting as the local executing agency with national research institute support. These agencies and institutions provided basic information and key inputs to this case profile, but the authors alone are responsible for the opinions expressed.

GENERAL CONTEXT OF CASE PROFILE

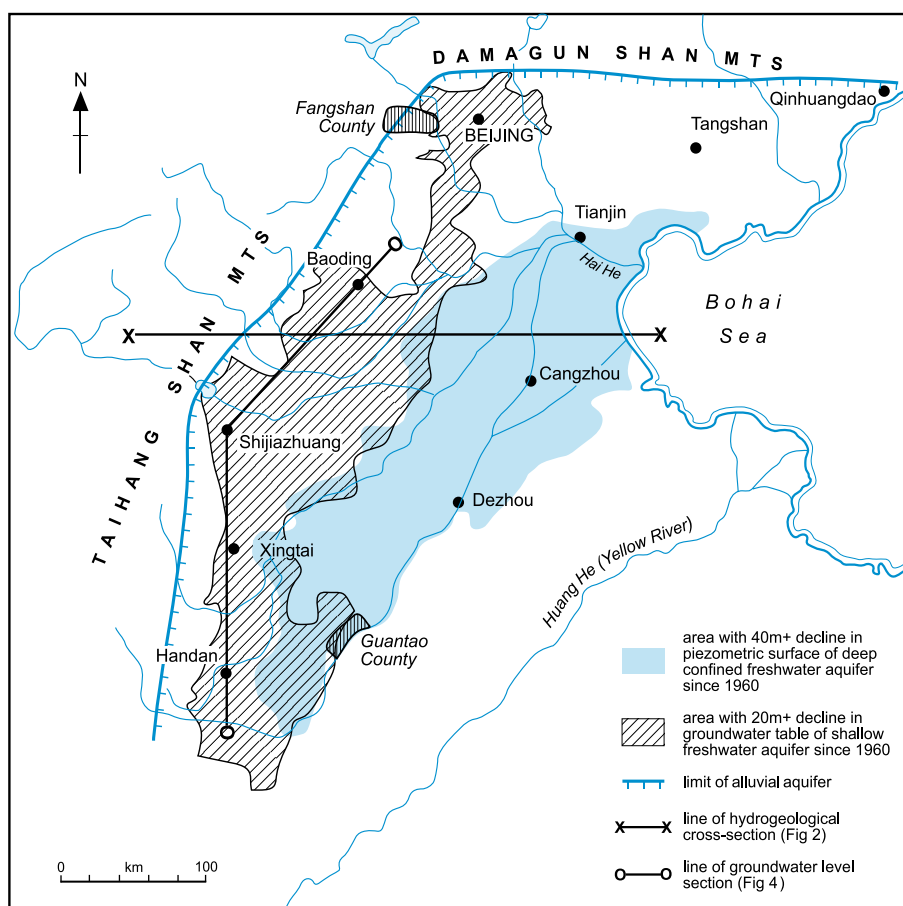
The Groundwater Resource Management Challenge

- The sustainability of intensive groundwater development for irrigated agriculture from the very extensive quaternary aquifer system of the North China Plain constitutes one of the world's major water resource management issues. The area has a total population in excess of 200 million, and is the predominant national center of wheat and maize production and an extremely important industrial region. The approaches to groundwater resources management discussed constitute an attempt to buffer the potentially-serious socioeconomic impacts that are likely to be experienced if (essentially) uncontrolled abstraction continues.
- Very extensive and temporally persistent falls in groundwater levels in both the shallow unconfined and deep semi-confined aquifers (Figure 1), and their associated side-effects, are giving grounds for serious concern. Reductions in groundwater extraction are required involving widespread introduction of 'real water-saving measures' (with appropriate incentives and monitoring of effectiveness), together with further enhancement of aquifer recharge with excess surface runoff and (where feasible and carefully-managed) urban wastewater. In particular it has been recommended that groundwater in the deep freshwater aquifer be treated as a strategic water-supply reserve, which in the longer-term should only be tapped for:
 - high-value small-demand uses, where no other readily alternative resource exist
 - alleviation of water-supply shortages in extreme drought conditions.

While adoption of this policy is pressing, its implementation is not straightforward and in the longer run is likely to result in a change in the balance of economic activity in part of the region.

- During the last 25 years China's legal and institutional framework for water resources has been evolving from fragmented to integrated management, and sufficient elements seem to be in place to allow complementary 'top-down' and 'bottom-up' approaches. But groundwater management in particular still has to overcome certain institutional impediments, by establishing an implementable use permit system, strengthening economic tools, increasing stakeholder participation, reconciling administrative boundaries with hydrogeological realities, and overcoming 'institutional stiffness'. The lessons gained in this process could be valuable inputs to nationwide efforts on designing an operational water rights system for the implementation of the new Water Law of August 2004

Figure 1: Sketch map of the North China Plain showing distribution of areas exhibiting marked aquifer depletion

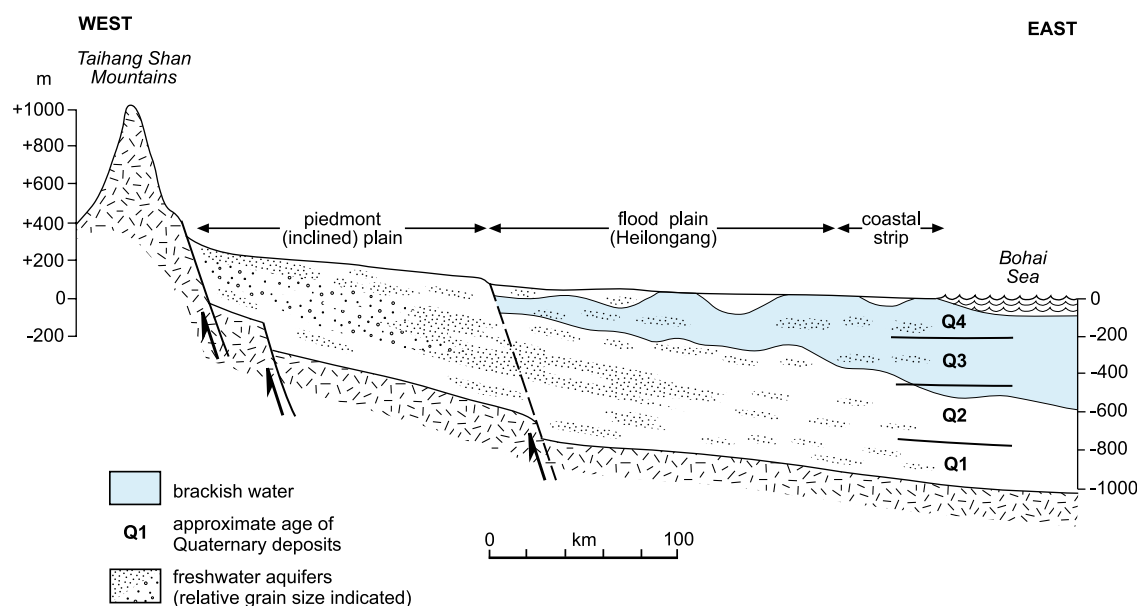


Hydrogeological Structure of North China Plain

- This case profile relates primarily to the North China Plain within the Hai river basin, including Beijing and Tianjin municipalities together with most of Hebei and western Shangdong provinces. This semi-arid area of northeastern China is characterized by cold dry winters (December-March) and hot humid summers (July-September). This area (and the entire region) comprises three distinct hydrogeological settings (Figure 2):

- the gently-sloping piedmont plain with major alluvial fans below a mountain escarpment
- the main alluvial plain (or so-called Heilonggang) with many abandoned river channels
- the coastal plain around the margin of the Bohai Sea.

Figure 2: Cross-section of the North China Plain showing the general hydrogeological structure



- Below most of the Heilonggang the sequence includes a brackish-water body, overlain by lenses of fresher groundwater and everywhere underlain by a deep freshwater aquifer. The following general observations can be made about the hydrogeology of the complex Quaternary aquifer system of the North China Plain (Figure 2):
 - permeability (hydraulic conductivity) and storativity (specific yield) increase in the direction of the escarpment bounding the aquifer system to the west and north
 - infiltration capacity and natural recharge rates (from excess rainfall and river flow) also tend to increase in the same direction
 - at some distance from the escarpment sufficiently consistent and thick aquitards are present to separate the aquifer into layers, with the groundwater of the deeper freshwater aquifer demonstrating hydraulically a more confined behavior
 - below most of the Heilonggang and coastal strip the sequence includes an overlying brackish water aquifer of large geographical extension, and the latter area may also have localized intrusions of more recent sea water
 - this brackish water aquifer is overlain by lenses of fresher groundwater, associated with the many existing and historic surface water channels and major irrigation canals.

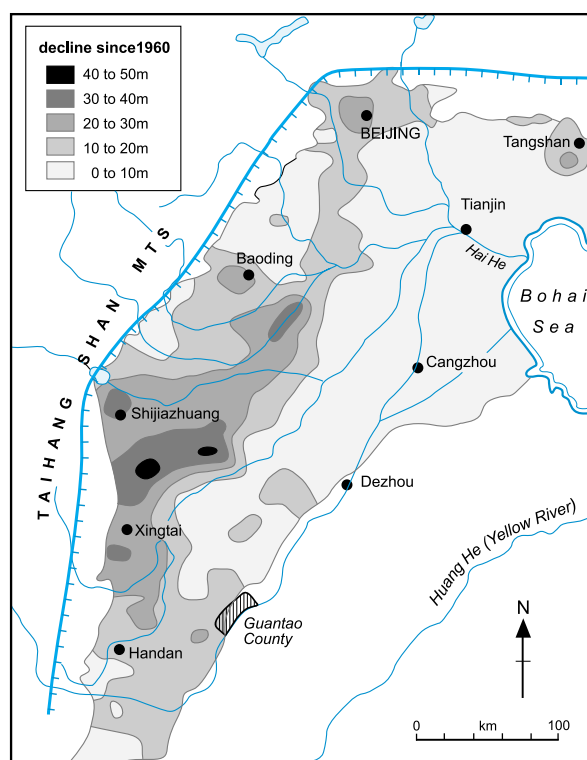
GROUNDWATER RESOURCE ISSUES & CONCERNS

- Both population and economic activity have grown markedly in the past 25 years, and much of this development has been heavily dependent upon groundwater resources. The enormous exploitation of groundwater (estimated in 1988 at 27,000 Mm³/a in the Hai He basin) has reaped large socio-economic benefits in terms of farming employment, poverty alleviation, grain production, and potable and industrial water-supply, but has also encountered increasing difficulties. The principal concerns fall mainly into the following categories :
 - falling groundwater table in the shallow freshwater aquifer
 - declining groundwater levels in the deep freshwater aquifer
 - risk of aquifer salinization as a result of inadequately-controlled pumping.
 These issues do not affect the three main hydrogeological settings equally.

Diagnosis & Economic Significance of Falling Water-Table in Shallow Aquifer

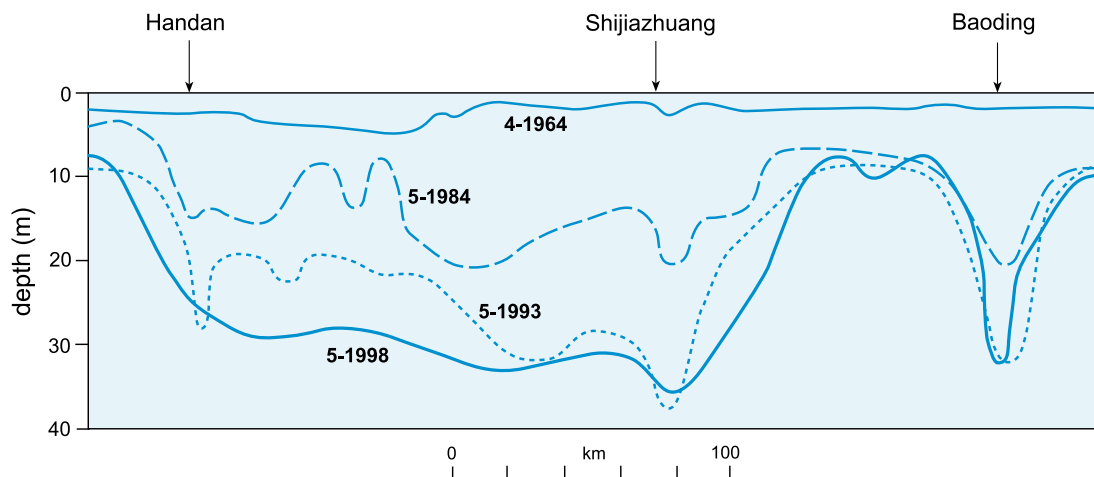
- Over most of the rural areas of the piedmont plain, and stretching onto the alluvial flood plain, the shallow aquifer has experienced a water-table decline of more than 15m over the past 40 years (Figure 3). Much greater declines have been observed in most urban centres (Figure 4). While significant (and in some cases delayed) lowering of groundwater levels is often necessary with major groundwater development, it has been independently estimated that in 1988 average groundwater abstraction exceeded recharge by some 8,800 Mm³/a in the Hai river basin as a whole. Using what is considered to be a reasonable range of values for specific yield of the strata drained (increasing

Figure 3: Cumulative water-table lowering of the shallow aquifer of the North China Plain – 1960-2000



westward from 0.08-0.18), the continuous long-term water-table decline of 0.5 m/a equates to an average recharge deficit of 40-90 mm/a.

Figure 4: Historical evolution of water-table in shallow aquifer along north-south transect of North China Plain



- It is instructive to compare this estimate of aquifer recharge deficit with estimates derived from a county-level water balance calculation based on crop water requirements in relation to annual rainfall, bearing in mind that at present about 60% of the land is cultivated with groundwater-irrigated winter wheat (Table 1).

Table 1: Simplified local water balance for typical current cultivation regime on the North China Plain

PARAMETER	AVERAGE VALUES (mm/yr)	
	Northern Parts	Southern Parts
Local Water Availability (Rainfall & Snowfall)	620	560
Crop Water Demand (100%SM + 60%WW):	665	665
Evapotranspiration-Summer Maize (SM)*	(460)	(460)
Evapotranspiration-Winter Wheat (WW)*	(340)	(340)
Deficit of Crop Demand – Local Availability **	45	105

* includes estimate of crop-beneficial and non-beneficial evapotranspiration for current cultivation regime, but assumes zero evaporation from fallow fields and other land uses

** assumes no surface water inflow/irrigation nor regional groundwater inflow from alluvial fans/mountain escarpment, and no surface runoff from the local area concerned

- Such simple water balances do not take all factors adequately into account, and numerical aquifer models are required (and being developed) to evaluate the groundwater resource situation in more detail. Nevertheless, it is evident that:
 - the possibility of significant groundwater inflow from upstream (reducing the deficit indicated) decreases markedly with increasing distance from the mountain escarpment and alluvial fans
 - the assumption of no surface water inflow and irrigation in the county area under consideration

- (which could also have reduced the deficit) is now realistic for extensive areas (but not all) of the plains, because various of the rivers issuing from the neighboring mountain escarpment have been impounded and much of their runoff diverted for urban water-supply
- the deficit may be higher than indicated for much of the flood plain area, since here a proportion of the local annual rainfall generates surface runoff
 - the residual deficit (after taking account of all of above factors) is currently being made-up by depletion of aquifer storage reserves.
- On the Heilongang (an area with average rainfall below 560 mm/yr) problems of falling water-table in the phreatic aquifer are less marked (Figure 3), primarily because of more limited aquifer potential due to thin and patchy development. The depression of the water-table has coincidentally reduced the problems of soil salinization, but this extensive area is still one which is characterized by the presence of brackish water at relatively shallow depth and salinization of the shallow freshwater aquifer can result from:
 - vertical up-coning from the underlying brackish water formation under heavy abstraction
 - sea-water intrusion, but only locally along some sections of the Bohai Sea coast
 - recycling of salts from irrigation water, aggravated by pumping of brackish groundwater for irrigation.
 - The pumping of shallow brackish water for irrigation use during parts of the crop growth cycle (or for mixing with fresh groundwater) has also recently been introduced locally, to reduce the overdraft of freshwater aquifers. However, where the shallow freshwater aquifer is present this poses a serious hazard of secondary aquifer salinization and an especially complex long-term management issue.
 - A preliminary estimate of the potential economic significance of water-table depletion and the unsustainable use of groundwater resources can be made using the limited available data and making various assumptions (Table 2). The major consumptive use of groundwater on the North China Plain is currently the irrigation of cereal crops, for which a cropping intensity of about 1.7 is achieved with a combination of (regularly-irrigated) winter wheat and (occasionally-irrigated) summer maize, and one way or another some 1000 m³ of water is needed to produce 1 metric ton of grain^{*}.
 - Not all of the winter wheat production would be at risk because of the eventual loss of groundwater currently being mined from aquifer reserves, since the proportion of total water demand per crop

Table 2: Estimation of value of winter wheat production in groundwater depletion zone of North China Plain

FACTOR	ESTIMATE
Current Area under Cereal Cultivation within Groundwater Depletion Zone	5.0 M ha
Proportion of Area with Irrigated Winter Wheat	70%
Present Average Winter Wheat Yield	4000 kg/ha
Typical Unit Value of Winter Wheat	US\$ 120*/metric ton
Total Value of Winter Wheat Production within Groundwater Depletion Zone	US\$ 1,680* M/yr

* for CY (Chinese Yuan) multiply by 8

(340 mm) being provided from this source is probably some 20-30%. It is uncertain what the corresponding level of crop loss would be, and a figure of 50% (valued at US\$ 840 million) has been discussed. But direct groundwater recharge from rainfall on the piedmont plain would still be available – this averages some 50 mm/a and this renewable resource would support 1-2 (as opposed to 3) applications per crop. Carefully-managed ‘deficit irrigation’ could allow the provision of supplemental water at critical crop growing periods and thereby the limitation of yield reductions.

- The cropping of summer maize (with current yields of around 5,000 kg/ha and a market value of US\$ 110 (CY 880) /metric ton is far less dependent upon groundwater, but reduced availability for irrigation would also have a substantial impact on production in drought years.
- The question also arises of how much further could the water-table of the shallow freshwater aquifer fall before it becomes totally uneconomic for farmers to irrigate cereal crops, assuming no other serious side-effects (such as irreversible aquifer deterioration and environmental impacts) occur earlier. It is evident that with a water-table depth of around 50 m (and irrigation energy costs of more than US\$ 20 (CY 160)/ ha/lamina), farmers are reducing from 3 (or more) to 2 irrigation applications and beginning to seek water-saving measures.

Assessment & Environmental Significance of Deep Freshwater Aquifer Depletion

- The entire plain is underlain by a deep freshwater aquifer of very low salinity and apparently excellent quality (except for the occurrence of excessive fluoride content for potable supply in some places). Distant from the escarpment, the groundwater in this aquifer exhibits an increasingly confined hydraulic condition and occurs beneath an intermediate brackish water aquifer across much of the Heilongang and coastal plain (Figure 1), reaching to at least – 400 m msl (well below the Bohai sea-floor at around –30 m msl).
- In recent decades this deep aquifer has been rapidly developed for urban and industrial water-supply, and where the shallow aquifer is thin or absent for agricultural irrigation. Extraction of deep groundwater in the Heilongang has led to a rapid decline of the aquifer piezometric surface (Figure 2). In the rural areas an average value for deep aquifer groundwater level decline of more than 3 m/a during 1970-80 has now been reduced to 2 m/a. Given the confined nature of the deep freshwater aquifer system, such drawdowns can be caused by relatively modest abstraction rates of the essentially fossil groundwater, but in this case generate a disproportionate risk of:
 - environmental damage from land subsidence due to aquitard compaction
 - groundwater salinization through inducing downward movement of the overlying brackish water interface (Figure 1) – which has been monitored at average rates of 0.5-1.5 m/a for the past 20 years at some locations.
- There is question of whether any significant freshwater replenishment is reaching the downpied parts of the deep aquifer. The recharge area of the overall aquifer system is found on the upper side of the piedmont plain and here the deep aquifer exhibits a semi-unconfined condition and is recharged by downward leakage from the alluvial fans of the major rivers. The turnover time of groundwater in the shallow aquifer is believed to range from 200-1,000 years or more, but the proportion penetrating deeper is estimated to be much older and is believed to have been largely

emplaced in a colder wetter epoch more than 10,000 years BP.

Specific Example of Guantao County

- As an example of more specific problems, the case of the Guantao pilot groundwater management area is introduced. This county is representative of Heilonggang areas using the shallow aquifer but also dependent on the deep freshwater aquifer, and is the focus of current efforts to develop effective approaches to stabilizing aquifer water-levels and to achieving a sustainable regime of groundwater use. Guantao County is located in the southern part of Hebei Province (Figure 2), with a total area of 456 km² and an average precipitation of 550 mm/a. It has a shallow freshwater aquifer underlying about 60-70% of its land area, but with the underlying brackish-water aquifer at relatively shallow depth, and beneath this the deep freshwater aquifer (of very low salinity and good quality except sometimes for fluoride content) is everywhere present.
- By 2002 the GCWRB had issued 332 groundwater abstraction permits mainly for crop irrigation use (each one covering groups of up to 20 wells) representing the total allocated extraction rate of 89.1 Mm³/a (Table 3). However, the total actual groundwater abstraction was estimated to be 32% larger, with 5.6 Mm³/a derived from the deep freshwater aquifer (of which 40% was used for irrigation, 20% for industry and 40% for domestic supply). In order to address the groundwater overdraft problem the Guantao County Peoples Congress passed regulations in 2003 for water administration and management of deep groundwater.

Table 3: Comparison of actual and permitted groundwater abstraction for Guantao County in 2002

WATER ABSTRACTION (MM3/A)	IRRIGATION	INDUSTRY	DOMESTIC	TOTAL
Total Permitted (including surface water)	89.0	3.4	8.7	101.1
No. of Groundwater Licenses Issued	277	54	1	332
Total Permitted for Groundwater	86.0	3.4	8.7	98.1
Estimated Actual Groundwater Use	95.7	3.6	18.3	117.6
Withdrawal from Deep Aquifer	2.3	1.1	2.2	5.6

APPROACHES TO GROUNDWATER RESOURCE MANAGEMENT

- The objective of this paper is to concentrate upon diagnosis and mitigation of groundwater resource depletion issues. The applicability of the main mitigation options are summarized in Table 4 – urban and industrial demand management measures are also required but given the overall trend to urbanization and industrialization in the region the related total demand is likely to grow further. It is recognized that an integrated approach, including consideration of upstream surface water utilization and management in the Huang river basin in particular, will be required for complete resolution of some of the problems.

Table 4: Summary of main mitigation options for groundwater resource depletion on the North China Plain

OPTION	GROUNDWATER RESOURCE DEPLETION	
	SHALLOW AQUIFER	DEEP AQUIFER
AGRICULTURAL DEMAND MANAGEMENT		
Agricultural Water Savings	+++	++
Agriculture Crop Changes*	++	++
Partial Ban on Cereal Crop Irrigation	++	+++
SUPPLY-SIDE MEASURES		
Enhancing Surface Water Recharge**	++	O
Use of Wastewater for Recharge***	++	O

+++ major potential

++ good potential

+ minor potential

O not important

* only viable near major cities where market exists

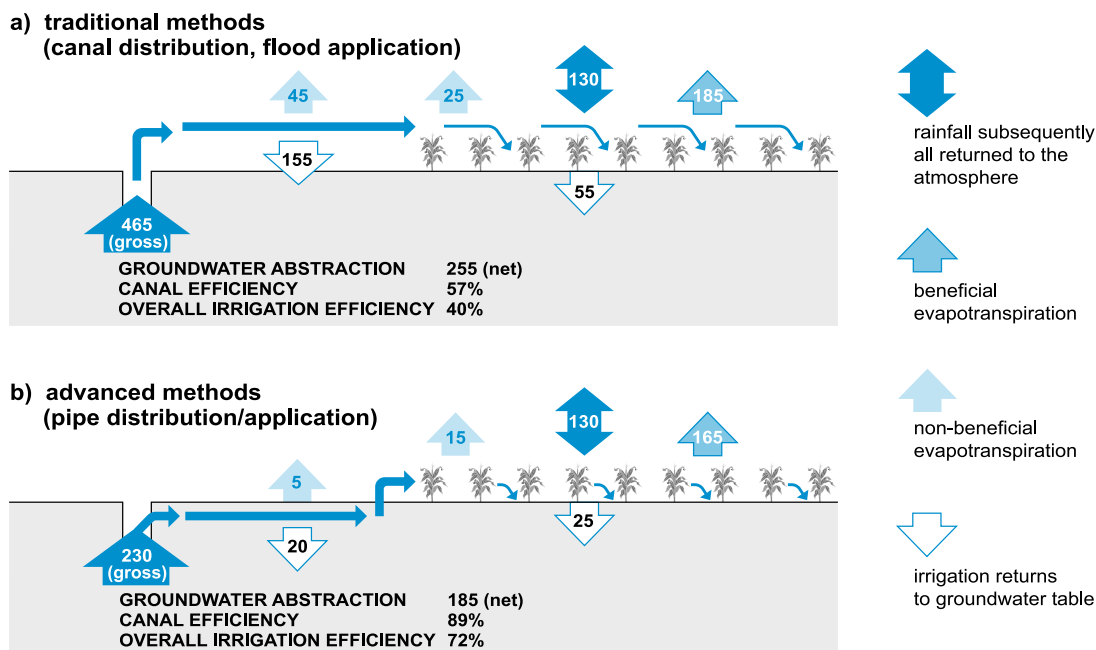
** in many instances will need more reliable source of surface water (than major flood events) which will require surface engineering measures

*** requires pilot schemes to adapt techniques to local conditions

Agricultural Demand Management

- There is considerable evidence that **agricultural water-saving measures** can substantially reduce non-beneficial evapotranspiration and effect 'real water savings' of 50 to 80 mm/yr for areas under groundwater and surface water irrigation respectively. Such measures are considered capable of reducing the rate of decline in the deep confined aquifer and of making a contribution to stabilizing the shallow water-table. But since they depend heavily on water-user participation and require well discharge metering to confirm their effectiveness, they are likely to take some years to implement fully. Nevertheless it is considered that there is everywhere considerable scope for agricultural water-savings through:
 - 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 and water scheduling
 - agronomic measures: such as deep ploughing, straw and plastic mulching and the use of improved strains/seeds and drought-resistant agents.
- The World Bank Water Conservation Project Mid-Term Review (May 2004) considered that the introduction of such measures appears to have reduced evapo-transpiration (ET) by 30-45 mm/yr in various pilot areas (while concomitantly increasing farmers' income to above the national average) and this should greatly aid balancing of groundwater replenishment with abstraction. The ways in which improving irrigation technology can reduce groundwater demand and lead to 'real water resource savings' have also been evaluated at an experimental field site (Figure 5).
- However, at larger scale the reductions in actual evapotranspiration and real groundwater resource savings are more difficult to verify in the short term. The current monitoring method (based on measuring water-table fluctuations and estimates of specific yield) has the advantage of being

Figure 5: Experimental example of improved techniques for winter wheat irrigation leading to real groundwater resource savings



straightforward for CWRBs to apply, but is not sufficient on its own to determine unequivocally the amount of real groundwater resource saving in a given year, since groundwater level observations contain too much noise and can be subject to a large number of external influences. An additional complementary approach based on periodic field survey of soil moisture profiles has been designed, which aims to generate independent evidence of real water-savings whilst accepting that the longer-term objective is groundwater table stabilization.

- If larger water resource savings and more rapid reductions in groundwater abstraction are needed, then consideration should also be given to **changes in crop type or land use**. There is significant potential to substitute irrigated cereal crops with higher-value, lower water-demand, crops under greenhouse cultivation on reduced land areas – but there may be significant market, transport and storage limitations on this option, and it is only likely to be feasible at present in the vicinity of major urban centers.
- An even more radical option would be to **ban the irrigation of cereal crops** in the most critical groundwater areas, and thus reduce the overall proportion of the land area used for cultivation of irrigated winter wheat holding a larger part of the land area fallow until the planting of the largely rain-fed summer maize crop.

Supply-Side Aquifer Recharge Measures

- While agricultural water-savings are capable of making a major contribution towards reducing the decline in groundwater levels, they may not everywhere be sufficient to close the imbalance of groundwater resources. Thus complementary actions such as **artificial aquifer recharge of excess surface run-off** in the summer months of the wetter years, deploying relatively low-technology methods (Table 5), may also be required. China already has considerable experience of aquifer recharge enhancement dating from the 1970s onwards. The techniques used vary considerably with general hydrogeological setting and specific sub-soil profile, but include small gully dams, diversion canals, rubber-dams, village pits and ponds, flooding of maize fields following wet season storms, and diversion of riverflow to flood-retention reserve land.

Table 5: Aquifer artificial recharge techniques potentially suitable for the North China Plain

RECHARGE TECHNIQUE	SOURCE OF WATER FOR RECHARGE		
	river flow	flood runoff	urban wastewater
Land Spreading	++	++	+++
Ponds/Pits & Canals/Trenches	+++	++	++
SAT* Lagoons	O	+	++
Injection Boreholes	++	O	O

+++ Highly applicable
++ Moderately applicable
+ Somewhat applicable

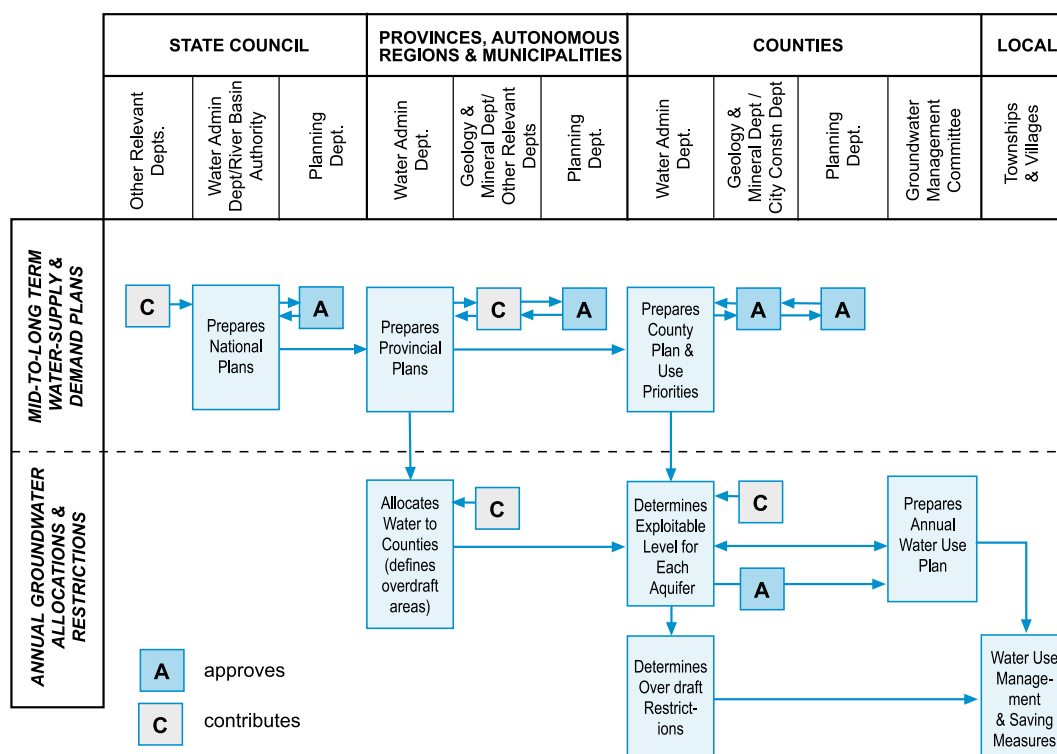
* soil-and-aquifer treatment utilized by
controlling infiltration rates and periods
O not applicable

- All of these measures should continue to be encouraged, especially in the piedmont plain environment where the conditions are very suitable. The issue generally is not so much the feasibility of artificial aquifer recharge but more the regular availability of water to recharge. Moreover, some flood-water flow to the sea is needed to flush sediments and pollutants from riverbeds, and this is a further competing consideration.
- The current rate of generation of urban and industrial wastewater in the Hai river basin alone is very large indeed (in the order of 10,000 million m³/yr), but its quality varies widely. Nevertheless, most urban wastewater should be regarded as a valuable water resource which, after primary (or perhaps secondary) treatment, can be reused directly for the irrigation of certain agricultural crops. Such irrigation, normally results in high rates of infiltration and recharge to aquifers when practiced on the permeable soils like those of the piedmont plain. Moreover, the wastewater can, under suitable hydrogeological conditions, be used for some techniques of aquifer recharge. The natural process of infiltration through the vadose zone will normally effect secondary and tertiary treatment for most wastewaters. The approach described has the additional benefit of limiting uncontrolled wastewater discharge and/or reuse, which represents a serious groundwater pollution threat. Following on from this there will be need for the promotion of some relatively large-scale pilot demonstration projects at sites believed to be representative of wastewater types and hydrogeological settings for the North China Plain.

INSTITUTIONAL ARRANGEMENTS FOR GROUNDWATER MANAGEMENT

- It must be stressed that management interventions described above, which are variously aimed at:
 - generating real groundwater resource savings at local field scale (through reducing non-beneficial evapotranspiration)
 - augmenting groundwater resource availability through enhancing aquifer recharge

Will only be effective in achieving aquifer hydraulic stabilization if they are accompanied by administrative actions to reduce actual groundwater abstraction and not use all of the water savings simply to amplify the land area under irrigated agriculture or to transfer the abstraction right to a consumptive industrial user.
- Since the late 1980s, water resource administration in China has been moving from fragmented to integrated, through legal revisions and restructuring of government organizations. The Water Law (1988) provided for water resources administration through various departments at different levels. After the restructuring of government organizations, which commenced in the late 1990s, and revision of the Water Law (2002), all functions of water administration (except for wastewater discharge) were assigned to the Ministry of Water Resources (MWR) and departments of local government.
- Specific legislation on groundwater, however, remained weak and at national level there were no laws and regulations on aquifer management. The Regulations for Implementation of Water-Drawing Permits (RWPN), issued by the State Council (1993), provided the basic legal framework for water rights administration – the MWR has issued several supporting regulations, and some provinces and counties have also issued local regulations for the implementation of groundwater abstraction permits. This has resulted in a statutory ‘top-down’ approach to groundwater management which does not engage with ‘bottom up’ actions. It will also be necessary to overcome a degree of ‘institutional rigidity’ by:
 - Reconciling individual government department targets for development and production with those for longer-term groundwater resource sustainability
 - Accepting that groundwater resource administration is much more than ‘clerical work’, and is in reality a complex multi-faceted social task for which close relationships between technical and administrative personnel are needed.
- According to the Water Law (2002), water resource allocations should follow the corresponding ‘river basin plan’ and the ‘water demand-and-supply mid-term plan’. The procedure provided at national, provincial and county levels (example of Hebei Province and Guantao County) is shown in Figure 6. It can be seen that the planning process does not include either feedback between different government levels or the participation of users. At county level the Department of Land & Mineral Resources should play a role, but there are now usually no groundwater specialist personnel in this agency at county level, so the provision is not fully consistent with reality on the ground.
- On the other hand, day-to-day groundwater administration in China is carried out at the local level by the County (or District) Water Resources Bureau (CWRB). This highly-decentralized (and in effect ‘bottom-up’) approach is potentially a major asset, presenting opportunity for close interaction with actual users and potential polluters of the resource. However, there are still

Figure 6: Planning procedures for groundwater resource allocation in China


various institutional needs that must be addressed to achieve effective coordination of groundwater resource management.

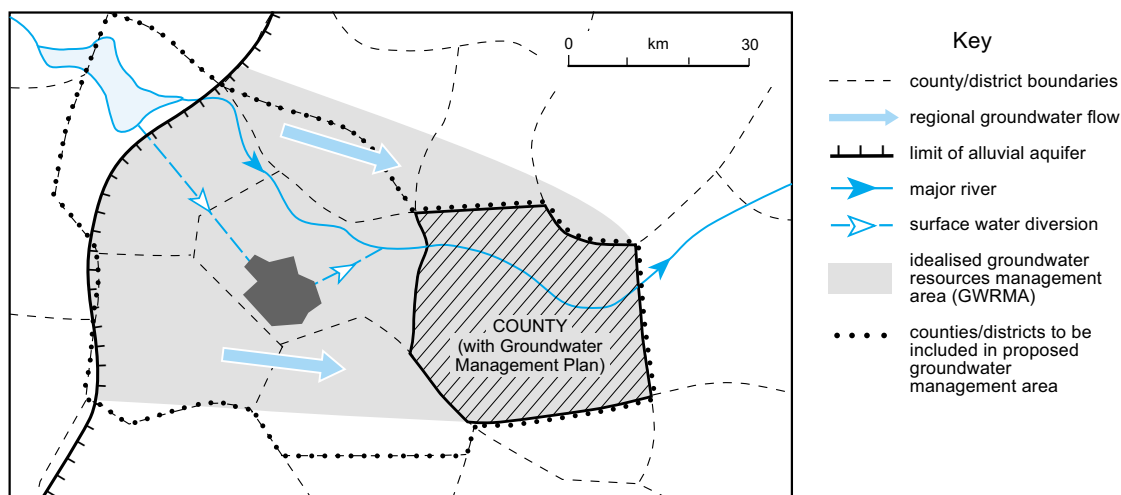
Reconciling Political & Hydrogeological Boundaries

- The level of groundwater depletion on the North China Plain is such that the action of an individual CWRB alone will not be sufficient to stabilize the local groundwater table. For effective resource administration, groundwater management areas (GWRMAs) need to be defined and established taking into account hydrogeologically-based boundaries and ‘upstream-downstream’ considerations, since these provide a more rational basis for integrated water resource management (Figure 7).

The following factors need to be taken into consideration in the process of defining boundaries:

- A GWRMA will, of course, often contain more than one aquifer unit; for the most part it appears that reasonable GWRMA could be defined respecting county boundaries and (for administrative convenience) largely remain within a single province, but the same cannot be said of municipalities.
- At the urban-rural interface there is need to promote groundwater resource reallocation to the more productive commercial and industrial users, through schemes in which the corresponding municipality finances improvements in agricultural irrigation (generating real water savings) in return for abstraction and use rights of a proportion of the groundwater saved

Figure 7: Theoretical example of consolidation of local CWRMBs into a GWRMAs

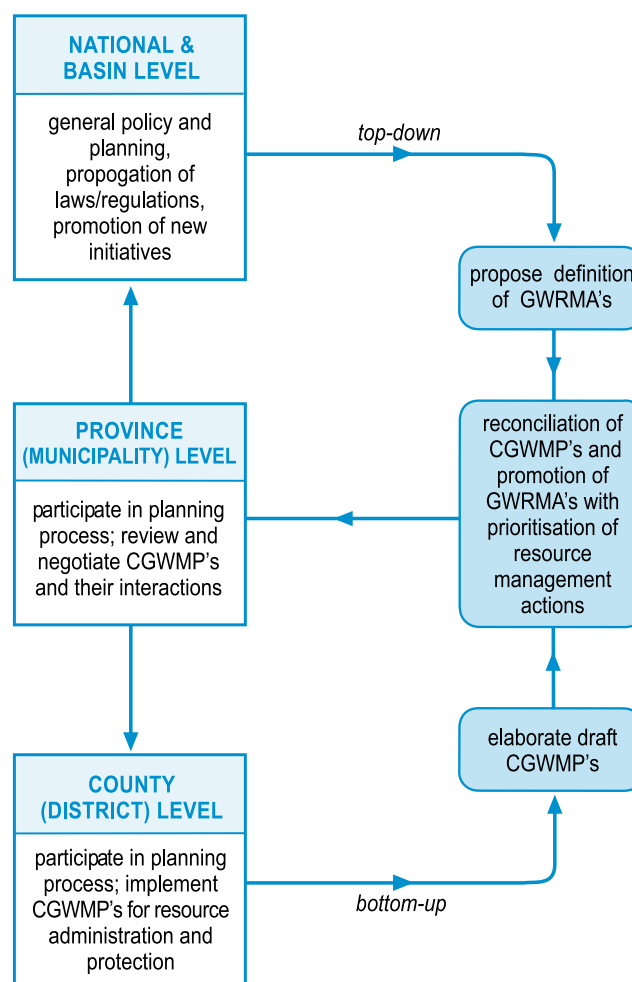


- In areas with adequate knowledge of groundwater resource availability, use and behavior, the introduction of tradable water rights could be considered, provided a sound water-use rights system had been consolidated
- To make aquifer recharge enhancement feasible, the financial, administrative and legal basis for using surface runoff in upstream counties principally for the benefit of groundwater users in downstream counties, must be addressed – and it will probably be necessary for the provincial authority to oversee this process
- similarly, the successful implementation of wastewater reuse schemes will require the relevant Environmental Protection Bureaus (Epps) to guarantee acceptable wastewater quality and treatment standards in the interest of the CWRB(s) authorizing the reuse – and appropriate arrangements will need to be in place for this to be possible, together with considerable training of staff on the operation and control of such schemes.

Integrating 'Top-Down' & 'Bottom-Up' Approaches

- The proposed approach is based upon the following key considerations as referred to in the possible scheme illustrated in Figure 8:
 - the identification and prioritization of GWRMAs should be conducted by the MWR with close interaction with the corresponding river basin committee (RBC) and the provincial water resource bureau (PWRBs)
 - target yields should be defined for each GWRMA (and component aquifer unit), through dialogue between the RBCs and the PWRBs, and this then related to groundwater abstraction permits and implemented by the CWRBs, raising any special concerns as necessary
 - while practical groundwater management is clearly best performed at county level, PWRBs should have a clearer role, including coordinating the management of resources shared by several counties within their jurisdiction and promoting training programs in resource management
 - in order to improve central policy (through sharing of success and difficulty), feedback from the county/district level via the PWRBs and the RBCs will be necessary

Figure 8: Preferred hierarchy of communication and action for the establishment of GWRMAs



- the longer-term MWR role with respect to groundwater resources management could be facilitating and monitoring the actions of the PWRBs, as well as promoting interchange at all levels.
- The MWR could establish more harmonised criteria for the administration of groundwater abstraction permits, especially as regards their period of guarantee, taking into account the minimum duration necessary to give financial institutions confidence to invest in the related development (including appropriate water-savings measures) and the need to reserve groundwater for human consumption:
 - more emphasis on the 'new roles' required of the CWRBs, in terms of support to water-user associations for resource management, monitoring of the status and use of groundwater resources, and in public and political education and awareness
 - the RBCs could play an important role in establishing and enforcing (under the direction of the MWR) more effective and integrated use of surface water, groundwater and wastewater resources between provinces or municipalities, using the leverage of financial allocations.

Implementable System of Abstraction Permits

- A simple robust permit system to address resource management is needed that:
 - ensures that effective agricultural water-savings measures are translated into permanent reductions in groundwater abstraction (reflected in permits) and not simply used to expand the overall area under irrigation or to increase water use in other sectors
 - complies with RWP (1993) by accelerating the issue of groundwater abstraction permits, based on comprehensive water well registers that many counties have already drawn-up, and by introducing computerized databases to facilitate permit administration and secure storage to safeguard records in view of their legal significance
 - achieves a consistent link between groundwater resource estimates and authorized abstraction rates on permits, prioritizing areas subject to marked aquifer depletion
 - establishes closer linkages between the agricultural extension service promoting water-saving measures and the process of issuing groundwater abstraction permits
 - implements local groundwater abstraction measurement and level monitoring, with dissemination of the information generated to water users
 - enforces water-saving universally, so individually conscientious users do not lose motivation.

Strengthening Economic Tools

- In the longer run it will be necessary to consider:
 - the provision of economic incentives (such as part financing and/or easy-access low-cost loan capital) for the installation of more efficient irrigation technology
 - the charging of a realistic 'groundwater resource fee' to generate finance for aquifer management monitoring and to serve as an incentive for reducing groundwater abstraction.

Increasing Stakeholder Participation

- It must be recognized that stabilizing the Quaternary aquifer of the North China Plain is a long-term process and that the demand management advocated will require appropriately trained staff in the CWRBs and public awareness raising programs for water-users, political decision-makers and the general public. In particular:
 - Farmers need to be well informed on the benefits of adopting more efficient irrigation methods and to grasp fully the 'real water saving' concept
 - The 'common pool' nature of groundwater requires that a mechanism for broader participation be established, including representation of urban and industrial users in addition to the (irrigation) WUAs.

Publication Arrangements

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