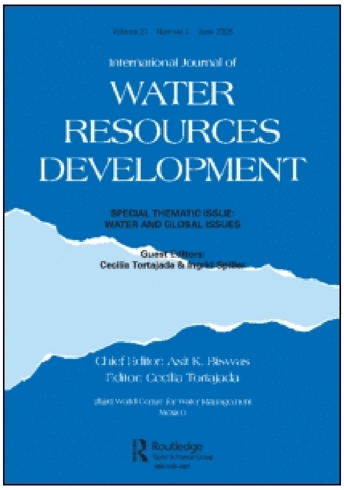

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Irrigation Development and Water Rights Reform in China

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ABSTRACT *This article describes the growth and importance of irrigation in China in terms of the expansion of surface water irrigation led by the state, and the more recent acceleration of groundwater irrigation led by individual farmers. Key management challenges and policy priorities are outlined, highlighting the importance of water conservation and integrated water resources management under the 2002 Water Law. The article then describes the basis for rights definition and allocation planning under the Law, and recent experience with implementation in surface water and groundwater contexts.*

A key conclusion is that the development of a modern water rights system in China is vital for mediating between the claims of competing uses, particularly at the agricultural–industrial–urban interfaces, and for meeting water conservation and reallocation objectives. At the same time, farmers within irrigation districts and in emerging groundwater economies need clearly defined rights to encourage investment in the farm economy and to provide security of supply. Implementing new systems in a country the size of China is a major challenge, however, particularly across large rural aquifers where groundwater development is increasingly opportunistic and farmer-led.

Introduction

Since the reforms of the late 1970s, China's economy has grown rapidly and household incomes have risen substantially. Indeed large scale poverty reduction, particularly in rural areas, has been one of China's greatest achievements, with the number of people below the poverty line estimated to have fallen from around 250 million in 1978 to 29 million in 2003 (NBSC, 2004).[1] China's rapid growth has come at a high price to its natural resource base, however, with growing water scarcity—exacerbated by pollution—reckoned to cost China around 2.3% of GDP (World Bank, 2007a).[2] Water scarcity is especially acute in the drier north of the country, where the success of irrigation development—both surface and groundwater—has contributed to today's problems.[3] In particular, spiralling industrial and urban demands are raising difficult political questions about how to protect water-dependent rural livelihoods and meet grain targets whilst releasing water to 'higher value' municipal users.

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Against this background, the 2002 publication of revisions to the 1988 Water Law marked something of a policy watershed. The revised law shifts the emphasis from supply-side solutions to integrated water resources management (IWRM) and water conservation, underpinned by a modern system of water rights. An effective system of water rights provides the basis for a number of different strategies for managing demand, including water pricing, permitting and trading. Perhaps more importantly, a water rights system provides a transparent, rules-based system for allocating water within and between uses. This is particularly important for irrigated agriculture as many of the allocation tensions now arising in China are, at their core, conflicts between irrigation and other uses, including the environment.

This paper describes how the development of a modern water rights system in China can strengthen rural people's claims to water and, at the same time, help meet water conservation and reallocation objectives. The paper begins with a brief summary of irrigation development in China, charting the rise of surface water irrigation development and the much more recent growth in groundwater exploitation. The paper then outlines some of the key management priorities that have emerged, and describes some of the more recent policy shifts that have occurred with respect to irrigation management, financing and investment priorities. The development of a modern water rights system in China is then discussed, with a review of the allocation system in general under the new Law and agricultural water rights in particular. Drawing on insights from the field, the paper then examines how policy is translated into practice, firstly in terms of the allocation of water rights to and within surface water irrigation districts (IDs), and then in terms of the allocation and management of groundwater rights. The discussion focuses mainly on experience from the drier north where competition for water, within and between sectors, is most acute. Finally, key conclusions and policy recommendations are summarized, recognizing the diversity of different irrigation 'systems' in China—from major surface water schemes to smallholder groundwater irrigation—and the need to strengthen both formal and informal rights to improve water resources management and support farm incomes.

Irrigation Development and Management Challenges

Irrigation Development

Securing food production for a growing population in the face of climatic uncertainty has long been a huge challenge for China. Although the country's land area is vast, farmland (the cultivated area) accounts for only 130 million ha, or 13.5%, of the land surface. Roughly 65% of this lies to the north of the Yangtze River, an area with only 20% of the country's total water resources but that produces around half of China's grain, including nearly all of China's wheat and maize. Irrigation development here has played a vital role in feeding the country and reducing vulnerability to uncertain rainfall. To understand how intensive development and control of water resources has arisen, however, we need to look to China's past.

The history of irrigation development in China is a long one, with records of irrigation (and flood control) stretching back over 4000 years. Successive dynasties and local rulers have organized troops and peasants to construct dykes, irrigation channels, water storage ponds and wells, first in the north of China (in the Yellow River and Huaihe (Huai) River

Basin) and then in the southern provinces to the Yangtze River. During the Tang Dynasty (818–907), for example, over 1000 separate irrigation projects were developed as state enterprises, and by the Song Dynasty (960–1297) over two million hectares of rice paddy could be irrigated under surface water schemes. Even today, irrigation and flood control works on the Min River in Sichuan Province are used much as they were originally designed (Clayre, 1984).

The Republic of China (1911–49) and the People's Republic of China (1949–present) continued Imperial China's tradition of state development and control of large works. During the 1950s, 1960s and 1970s in particular, irrigation and drainage schemes were vigorously developed. Between 1958 and 1985, for example, around RMB65 million was invested in irrigation and drainage, and between 1949 and 1996, the irrigated area increased from roughly 16 million ha to 51 million ha.[4] Over the same period, the agricultural sector experienced major institutional upheaval as rural collectivization during the 1950s—and eventually rural communization—gave way in the early 1960s to decentralization and the effective abandonment of people's communes. Subsequently, the Cultural Revolution witnessed the recentralization of farming practices and top-down controls until finally, under Deng Xiaoping, collectives were disbanded and household farming was re-introduced under the Household Responsibility System (Ash, 1993).

Initially, the break-up of collectives in the post-1979 reform period led to major increases in agricultural productivity and production as farmers regained control over land and targets were relaxed.[5] However, public investment in surface water schemes began to decline in the late 1970s as government focussed on the industrial sector and local funding for agricultural works dried up. In addition, ambiguities over system ownership and maintenance responsibilities created weak incentives for investment and upkeep which, to some extent, persist today.[6] The resulting deterioration of irrigation infrastructure, a significant decline in irrigated area in the early 1980s and declining terms of agricultural trade, contributed to the stagnation in China's grain production and a rise in food prices in the mid-1980s to mid-1990s (Lohmar *et al.*, 2003). Nonetheless, IDs of various sizes, drawing on surface water from rivers and reservoirs, still account for most agricultural water use, irrigating roughly 72% of China's irrigated land area (MWR, 2006b).[7]

The deteriorating state of surface irrigation systems in the 1980s was also a key driver of groundwater development in northern China (Lohmar *et al.*, 2003). That said, groundwater irrigation is attractive to farmers in its own right because of its reliability and 'controllability', with rural electrification providing a further catalyst for development over wide areas through motorized pumping (Calow *et al.*, 2006). The growth of groundwater-based, smallholder irrigation is therefore relatively recent, but hugely significant. In the 1950s, groundwater irrigation was virtually non-existent in northern China. In the mid-1970s, groundwater probably provided around 10–15% of irrigated supply in the water-short provinces of the north. By the mid-1990s, however, this figure had risen to around 40%, and in important downstream provinces such as Hebei, Shanxi, Henan and Shandong, where much of China's wheat is produced, the share of groundwater irrigated areas increased to around 70% (Lohmar *et al.*, 2003). As a result, Wang *et al.* (2008) suggest that, over the last 25 years, more wells have been sunk in northern China than anywhere else in the world.[8]

Up until the last 10 years or so, most groundwater development for irrigation (and domestic supply) has been publicly funded through investment in village-based, collectively owned and managed boreholes. Indeed the ubiquity of groundwater and its low development cost have made groundwater-based investment attractive to government agencies seeking quick, poverty-reducing impacts in rural areas (Box 1). More recently, however, private investment in groundwater infrastructure has increased, fuelled partly by rising farm incomes and partly in response to the falling fiscal capacity of village collectives, leading Wang *et al.* (2007a, 2007b) to conclude that private investment in and ownership of wells has become one of the most prominent features of the 'new' groundwater economy (see Box 1).[9] Today, the territory of China can be broadly divided into three types of irrigation zones, with major differences as regards irrigation dependency and the importance of surface and groundwater sources (FAO, 2004):

- The dry northwest regions and part of the middle reaches of the Yellow River, where average rainfall is less than 400 mm/year and perennial irrigation is vital for agricultural production; in these areas, major surface water diversions supply some of China's largest IDs, and groundwater development by village collectives and farm households has grown rapidly in importance over the past 30 years.
- In the North China Plain and northeast China, where precipitation ranges from 400 mm to 1000 mm/year but is monsoonal, and thus uneven; irrigation here is necessary to secure production, with 'on demand' groundwater access increasingly important in buffering rainfall variability and surface water shortages.
- In the middle and lower reaches of the Yangtze River, the Zhujiang (Zhu River) and Minjiang (Min river) and parts of southwest China, where supplementary irrigation (typically from rivers, reservoirs and ponds) is sometimes required for upland crops, and remains necessary for paddy fields, especially to increase cropping intensity.

This paper focuses principally on irrigation management in the first two zones. These are the areas where water supply is most constrained, and where there has been significantly more emphasis on improving the regulation and efficiency of water use.

Box 1. Groundwater development and cash cropping in northern Hebei. *Source:* Calow *et al.* (2006).

Across large swathes of northern China, groundwater exploitation has underpinned the intensification of agriculture, supporting farm incomes, generating rural employment and reducing poverty. Intensive development is relatively recent. In Hebei over the period 1990–2003, the contribution of groundwater to total water use rose from roughly 66% to 79%, while the contribution to irrigated agriculture rose from 63% to over 75%.

The benefits of groundwater irrigation, and the management challenges posed by dispersed rural use, are illustrated in the northern Hebei counties of Shanyi, Zhangbei and Kangbao. This area of the Mongolian Plateau, known as the Bashang, experiences long harsh winters and short humid summers, and the assurance of supply that groundwater provides for both irrigation and domestic supply is vital. Since the mid 1990s, farmers have been encouraged to shift into commercial vegetable production through subsidized well drilling and irrigation, funded by up to eight different government departments acting independently of the water administration.

While irrigated land remains a relatively minor component of the total arable area, its contribution to production and income is significant. In Zhangbei, for example, the irrigated vegetable area accounted for only 10% of the total arable area in 2003, yet contributed over 38% to total cropped production value.

Today, agriculture's share of total water withdrawals stands at around 65%, with approximately 44% of the cultivated area classified by the Ministry of Water Resources (MWR) as irrigated (MWR, 2006a, 2006b).[10] Around 50% of irrigated land falls within IDs (28 million hectares, out of a national total of around 57 million). MWR reports more than 5800 IDs with an area greater than 10 000 mu (675 ha), and 148 with an area of greater than 500 000 mu (34 000 ha) (MWR, 2006b). Most of the water used for irrigation is drawn from rivers and reservoir storage (roughly 80% in 2005),[11] although groundwater abstraction—as noted above—has grown in importance. In this respect, national averages mask significant regional and local variation in irrigation dependency and water source.

Management Challenges and Responses

The passing of China's Water Law in 1988, and its revision in 2002, signalled a renewed commitment to investment in agriculture and the introduction of new irrigation policies in the context of severe drought and growing water scarcity.[12] The 11th Five-Year Plan (2006–10) also sets out a number of policy goals and priorities for water resource management aimed at supporting rural livelihoods and encouraging the reallocation of water between sectors. These include (a) adopting a more unified management system; (b) shifting from supply-side to demand-side management; (c) integrating river basin management with regional management; and (d) establishing a preliminary system of water rights trading.

In terms of commitments, national investment in agriculture rose by 8.6% per year in the late 1980s and by 19.7% per year in the 1990s (Lohmar *et al.*, 2003). Both the 2002 Water Law and the 11th Five-Year Plan commit the government to further increases in its attempt to increase production and maintain self-sufficiency in grains,[13] raise rural incomes and reduce rural-urban inequalities. In addition, the government has taken steps to reduce the burden on farmers by abolishing a raft of locally levied agricultural taxes.[14] The political imperative to protect farmers' interests, however, has made it difficult to levy the Water Resources Fee (see below) on rural users or to achieve full irrigation cost recovery.

In terms of policy, investment priorities have shifted from new projects to the renovation and maintenance of existing surface water systems, with much more emphasis on local management, farmer participation, financing arrangements and water conservation. In particular:

- Operation and maintenance of lateral channels, water distribution and water fee collection is increasingly being taken away from village committees and put in the hands of private franchises and Water User Associations (WUAs). For example, WUAs piloted in the early 1990s in the Yangtze River Basin and Hunan Province, have received strong government backing as organs of democratic management, operating outside the traditional village-township-county line of government authority (NDRC, 2000; MWR, 2003). WUAs have been tasked with local cost recovery and channel maintenance in an effort to reduce government outlays, increase accountability between irrigation agencies, WUAs and farmers, and improve local management. The contracting of operation and maintenance responsibilities on lateral channels to private franchises—often individuals—has proved even more popular (Lohmar *et al.*, 2003; Shah *et al.*, 2004; Wang *et al.*, 2008).

- Irrigation district agencies—particularly in the north of the country—have been encouraged to operate on commercial rather than 'public provision' principles. Specifically, many agencies no longer receive core funding from government, relying instead on the fees collected by WUAs or local contractors. A common way of improving fee collection and cost recovery is to make delivery of irrigation water contingent on pre-payment (with some discretion for extremely poor households).
- Government has invested heavily in water conservation through various national schemes and programmes. For example, under the banner of 'Developing a Water Saving Society' and 'Reasonable use of surface water, limiting the use of groundwater and actively using water from the heavens', the National Water Savings Office (amongst others) in the Department of Water Resources Management (under the MWR) has implemented model projects for Water Saving Societies in a number of provinces, including the use of prepaid water tickets and intelligent card (IC) reading equipment to allocate quotas.[15]
- Embryonic water trading has been encouraged, with a number of pilot projects underway to evaluate the feasibility, costs and benefits of promoting rural-urban transfers (see Box 2). Interest in reallocation reflects, in large part, growing water shortages in China's cities. Wouters *et al.* (2004) notes that in 2004, more than 400 of China's 668 major cities were experiencing water shortages, with more than 100 cities—including major population centres such as Beijing, Tianjin, Xian, Taiyuan and Datong—experiencing 'severe' shortages.

The emphasis on water conservation and coordinated, rights-based management articulated in the 2002 Water Law also applies to groundwater management. However, while direct regulation can be pursued vigorously with those water users who are easy to identify and regulate—particularly in urban areas—dealing with large numbers of small users in rural areas is much more difficult, especially with growing private ownership of

Box 2. Changing investment priorities in Hetao Irrigation District, Inner Mongolia. *Source:* Calow *et al.* (2008).

In the Hetao area of Inner Mongolia, water has been diverted from the north bank of the Yellow River to support irrigated cropping for more than 2000 years. Indeed agriculture would be impossible in this arid area without irrigation.

Although eight large irrigation canals were constructed during the Qing Dynasty (1644–1912), the most significant investment and expansion occurred in the early years of the People's Republic. However, inadequate funding for operation and maintenance, and problems with soil salinization, led to major difficulties in the 1980s, with falls in both irrigated area and crop production.

Today, Hetao ID irrigates an area of some 8.61 million mu (0.58 million ha) with five billion m^3 of water from the Yellow River, supporting a population of over 1.2 million people. Major investment from the late 1990s to the present day of roughly RMB570 million has helped mitigate soil salinization, and the management bureau operates largely independently of government, raising its own revenues for operation and maintenance from users, organized into WUAs. Significantly, investment priorities have shifted away from system expansion to rehabilitation and water conservation, reflecting wider changes in government policy.

groundwater assets. One outcome is that groundwater development has continued apace, leading some authors to speculate that groundwater over-exploitation in northern China threatens the livelihoods of millions, and could lead to rising domestic and international food prices (e.g. Brown, 1995).[16]

What is the evidence for a groundwater crisis? A first point to note is the dearth of comprehensive, reliable and accessible data on groundwater conditions. This reflects both a lack of official monitoring, and the fragmentation of data holdings among many thousands of local and personal databases (MWR, 2001).[17] As a result, the most comprehensive assessments of groundwater conditions have been carried out through project-based field survey rather than by government agencies. One such project, discussed by Wang *et al.* (2008), involved a survey of groundwater use across six provinces, 60 counties and over 400 villages, covering the years 1995 and 2004. The authors conclude that while groundwater over-exploitation appears to be a growing problem in many villages (around 50% of the sample), problems are not universally experienced. In roughly 50% of villages, groundwater levels had shown little or no decline, and in some, groundwater levels were reported to have risen.

One area where groundwater overdraft (and pollution) clearly is a major problem is the North China Plain, home to more than 200 million people. Here, groundwater levels in the shallow aquifer have fallen by more than 15m over the past 40 years, with much greater declines in urban centres. Foster *et al.* (2004) estimate that the value of agricultural production that could be at risk from unsustainable groundwater abstraction in the depletion zone at around $840 million per year (at 2003 prices). Over such a vast area, concerted action to control pumping is required at the aquifer scale. Key questions concern the ability of government agencies to influence groundwater withdrawals, either through rights-based approaches or other mechanisms, an issue discussed further below.

Reform of Water Rights

China's decision to develop a semi-market economy and to integrate itself into the World Trade Organization (WTO) marked a break with the country's long tradition of Confucian and Socialist traditions of subordinating law to the exercise of state power (Wouters *et al.*, 2004). Since the late 1980s, China has embraced 'the rule of law' in line with western notions of the principle, creating legal frameworks in a number of resource management contexts, including water, where no frameworks existed previously (Wouters *et al.*, 2004). Hence the 2002 Water Law sets out a comprehensive framework for the planning and allocation of rights, with provisions on water resource ownership,[18] the rights of collectives to use water, water abstraction rights (both surface and groundwater), water resource planning, water resource development and use, water conservation and allocation, dispute resolution and administrative responsibilities. The allocation of water to agricultural users needs to be viewed in this broader context.

In terms of institutional arrangements, a restructured MWR, under the State Council, has the primary responsibility for water resources management, including ultimate responsibility for the preparation of water plans and the management of abstraction permits that balance demand and supply. River basin institutions and commissions,[19] such as the Yellow River Basin Conservancy Commission, are then authorized by MWR to manage all water resources (including groundwater) in their respective basins. Restructured Water Affairs Bureaus (WABs), at and above county level, are tasked with water resource administration within their political boundaries in accordance with basin plans. Importantly, WABs now manage both urban and rural water, and both surface and groundwater, under one roof.[20]

In terms of water allocation and permitting, water allocation occurs through basin and then regional allocation plans, through which water is allocated between administrative regions. Hence water in a trans-provincial river, such as the Yellow River (see below), is allocated between provinces or autonomous regions according to the overall basin plan, with provincial/regional plans then allocating water between prefectures, and prefecture-level plans allocating water between counties. In this respect, the 2002 Law builds on the basin planning model first introduced in 1998, but strengthens and extends it to all river basins (Shen & Speed, 2009).

In addition to allocating long-term rights via Water Resources Allocation Plans, a set (and related) process exists in some basins for determining the actual volume available for abstraction (or consumption) during any given year according to available and/or predicted supply.[21] The resulting Annual Regulation Plans may be adjusted during the year to bring the plan in line with actual water conditions. Hence agricultural users in an ID may be required to adjust their irrigation schedules according to available supply, particularly in drought years.

In terms of sectoral and user priorities, the 2002 Law states that the domestic water demands of urban and rural people should be satisfied first, with agricultural, industrial and environmental demands, as well as navigation requirements, considered thereafter. In practise, agricultural users in IDs have often found their entitlements curtailed first during droughts, and Lohmar *et al.* (2003) argues that agricultural use is typically viewed as a low priority by local government agencies keen to promote industrial development and wealth creation in 'higher value' sectors. This is also apparent in the general approach to designing new water infrastructure. Typically across China, reservoirs and supply schemes are designed to deliver urban and industrial water at a daily reliability of 97–99%, while agricultural water is usually only required to be provided at 75% reliability (WET, 2006).

Access to water resources by an individual or unit is regulated by a water abstraction permitting system, based on a regulation issued by the State Council in April 2006, and in accordance with approved water resources allocation plans and quotas. By law, all water abstractions require a water abstraction permit.[22] The 2006 regulation provides details on the process for granting and managing permits, and builds on previous (often unimplemented) permitting provisions.[23] In addition, the 2002 Law makes specific reference to the problems of groundwater overdraft, and identifies the circumstances under which groundwater withdrawals must be forbidden or restricted to ensure sustainability.

Permits for IDs are usually held by the government agency responsible for administering the district which, in turn, has its permit defined by the relevant basin commission. Farmers are then supplied a share of the water available to the ID under the permit. In some areas in northern China, an ID plan is developed specifying each WUA's or village's share of the available water. In a few pilot areas, another form of water right—referred to as water certificates—has also been granted to individual farmers, identifying their share of available water under a WUA entitlement. This is coupled with a water ticket system under which farmers pre-pay for the water they want in a particular year, season or watering. A farmer is allowed to purchase water tickets up to a limit, based on their certificate volume and seasonal availability (see below).

Holders of water abstraction permits are required to submit an Annual Water Use Plan to their administering authority. This is considered (together with actual water availability) in preparing the Annual Regulation Plan (in those basins where plans are actually made), which specifies the actual volume available to the permit holder for the year. At the level of the ID, annual or seasonal plans may then identify the actual water available that year and when it will be delivered, with some level of consultation undertaken with farmers to determine the duration and timing of irrigations. Increasingly, this consultation occurs between irrigation agencies and WUAs or, if WUAs have not yet been formed, with village committees. Again, this process is generally limited to the drier northern parts of China, with farmers granted entitlements under ID permits and annual or seasonal allocation plans, rather than formal, legally defensible rights. In many southern basins, in contrast, permits are not allocated to IDs despite the legal requirement to do so, and water use is generally based on an informal understanding and agreement of an ID's entitlement and priority (WET, 2006).

Rights Management in Practice: Insights from the Field

While the effects of the policy and legislative changes outlined above will take time to emerge, available evidence, though patchy, suggests that reforms are paying dividends. Moreover in irrigation and rights reform—as in other spheres—policymakers are learning through experimentation, showing a willingness to test alternative approaches through pilots, evaluate results and scale up what seems to work.

In this context, a growing number of projects are contributing to water rights reform and lesson learning and, although each has its particular characteristics, many share common principles. These include the assignment of water rights to specific institutions or groups within broader allocation plans; the use of water tickets and certificates to allocate volumetric rights in a transparent way; the use of consultation (in some cases) between the various water users and institutional partners; new monitoring and evaluation procedures to determine allowable withdrawals; and in some cases the use of trading to reallocate available supply between different users and uses. Specific examples are discussed below.

From River to Farm: Rights Allocation for Irrigation Districts

Rights allocation and management in the Yellow River Basin (YRB) provides perhaps the most sophisticated example of the application of a modern water rights system in China (WET, 2006). Drawing on recent work in Inner Mongolia, WET (2007) describe how rights are allocated firstly among provinces and regions according to a basin allocation plan, down to IDs through abstraction permits, and finally down to WUAs and individual farmers through informal contracts and area-based claims.

First, Inner Mongolia's share of water from the Yellow River is defined in terms of a long-term Allocation Plan, and annually through an Annual Regulation Plan. Hence in an 'average' year, Inner Mongolia receives 5.86 billion m^3 out of a total flow of 37 billion m^3. In a drought year, shares across regions are reduced, with ongoing shares within any given year detailed in the Annual Regulation Plan, published by the Yellow River Conservancy Commission (YRCC). This provides for monthly scheduling, based on monthly water use and reservoir operation plans prepared by individual provinces and, if necessary, 10-day or real-time operation.

Secondly, and within Inner Mongolia, the major surface water abstractors require water abstraction permits. Due to the large size of the entities that withdraw water there are only 17 permits, the largest of which are for the IDs of Hetao and Hangjin,[24] held by the Inner Mongolia Yellow River Irrigation Management Bureau (within the Water Resources Department). However, actual diversions under the permits are determined by an iterative process that sees bottom-up demand (from farmers and WUAs) revised through top-down adjustment and approval (under the Annual Regulation Plan). Specifically, the irrigation agency in each district prepares annual and seasonal allocation plans based on farmer consultation through WUAs, with plans then implemented through an iterative process of scrutiny and adjustment to account for supply restrictions imposed by the YRCC.

Finally, the allocation process within each ID combines bulk volumetric charging to WUAs established on branch canals with area-based charging for farmers on tertiary channels. The process sees WUAs purchase water tickets on behalf of farm members in advance of each irrigation, as part of what is both a pre-ordering and pre-payment system. Hence within each ID formal, volumetrically defined rights are not granted to individual water users because infrastructure is not in place to directly monitor flows at this level. Rather, the ID agency supplies water to WUAs on a contractual basis through annual and seasonal agreements (signed-off by agency managers and WUA chairmen, and publicly displayed), and the WUA takes responsibility for allocating shares to production teams and individual farmers. Such arrangements create a type of group right, albeit one of limited security, with individual farmers then asserting area-based claims through the WUA.[25] Farmers also have the right to cultivate land and choose what crops to plant, the right to use and repair irrigation infrastructure and the right to at least influence, through the WUA or franchise, local rules and irrigation service plans, including water scheduling.

The allocation process described above is now common in the water-scarce IDs of northern China. In particular, establishment of WUAs and private franchises has often gone hand-in-hand with the introduction of ticketing and pre-payment systems (Wang *et al.*, 2008). Field surveys in both Hangjin and Hetao IDs on the Yellow River indicate strong support from farmers, WUA leaders and agency staff, though reasons differ. For the ID agency, pre-payment systems increase cost-recovery and provide timely revenues, albeit at levels that fluctuate with ticket sales and provide little incentive to encourage conservation. Coupled with financial autonomy for the agency, there is clearly an incentive to provide a reasonable service to WUAs, and the farmers within them, to maintain revenue. Village leaders and WUAs also benefit by gaining a clear definition of their responsibilities and of the basis for financing irrigation management, and consequently a reduction in conflict at village level. For farmers, pre-payment systems also provide a direct link between irrigation charging and service delivery. Formerly, flat charges were often levied by the village leadership at the end of the year, and irrigation charges were bundled together with other payments (WET, 2007). Some commentators argue that it is new payment and incentive structures, rather than farmer participation and institutional design, that have raised the performance of IDs (Shah *et al.*, 2004; Wang *et al.*, 2008).

In some areas, efforts to improve rights definition and allocation have gone further. For example, in the case of Hangjin ID discussed above, a pilot project has recently been completed with the aim of accurately defining entitlements to water down to WUA level—the lowest volumetrically monitored points on the system (WET, 2007). In particular, a district water allocation plan has been prepared, assigning rights to water to WUAs and allocating water for distribution losses. Allocations to WUAs can now be formalized by granting water certificates to each WUA. The annual allocation process and the sale of water tickets to farmers would be undertaken within this framework.

Similar reforms have already been implemented in the water-scarce Heihe (Black River) Basin, spanning Qinghai and Gansu provinces and Inner Mongolia Autonomous Region (WET, 2006). Here, rapid socio-economic development in the river's mid-stream section led to major water shortages and disputes between upstream and downstream users, and the drying-up of important downstream ecosystems. In response, the State Council oversaw the development of a water rights system for the basin, including a water allocation plan for the main river trunk, the establishment of China's first water-saving society pilot in Zhangye, and water-saving irrigation 'sub-pilots' across several counties. In the Liyuan River ID (a typical pilot), this has involved (a) the determination of an allowable diversion for the ID, with a return flow requirement for downstream users; (b) quota allocation, within the cap, down to farmer WUAs at village level; (c) issue of water certificates to individual households, specifying rights and conditions of use; and (d) the introduction of water tickets based on annual and seasonal estimates of water availability under the permit, with provision for water trading (via tickets) coordinated through the irrigation agency.

A rather different approach to rights reform is underway in the Hai Basin Integrated Water and Environment Management Project, funded by the World Bank. A key element of this project is the distinction made between consumptive and non-consumptive water use, and the practical implications this has for the definition, allocation and monitoring of water rights when water conservation is a key objective. In particular, the distinction recognizes that only those savings in consumptive water use—specifically non-beneficial evapo-transpiration (ET) and flows to non-recoverable sinks—represent 'real' water savings which can prevent the over-exploitation of water resources within the basin. The project uses satellite remote sensing techniques to measure, target and monitor ET at the basin level and all the way down to individual farm plots, with the objective of reducing, over time, consumptive rights so defined. A similar ET-focussed approach has also been adopted on the World Bank-funded MWR Water Conservation Project to reduce the current over-exploitation of groundwater on the North China Plain (Foster & Garduno, 2004), discussed briefly below.

One objective of the Hai Basin initiative outlined above is to establish water markets based on the trading of ET quotas. Water trades of various hues have also been introduced in other parts of China, albeit on a limited basis and without a clear distinction between consumptive and non-consumptive use. In the YRB, for example, the Inner Mongolia Water Resources Department has initiated a pilot project in which downstream industries are encouraged to invest in upstream channel lining within IDs. In return, the industries receive—or bank—the water saved from reduced leakage.[26] Under the guidance of the YRCC and MWR, Inner Mongolia has now assigned water withdrawal quotas among six riverside cities, drafted a plan for water transfers, and established an Office for Water Transfer Affairs to manage transfer funds and oversee implementation. Under the scheme, Hangjin ID has transferred roughly 78 million m^3 per year to downstream industries, although rights to traded water remain ambiguous. In particular, it is unclear whether the permits assigned to IDs such as those in Hangjin are owned by the irrigation agency, or just held by such organizations on behalf of farmers in a form of 'trusteeship' (WET, 2006, 2007).

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While direct regulation based on defining and managing volumetric rights can be pursued vigorously with those users who are easy to identify and regulate—such as in the case of a single off-take point for a large irrigation district—dealing with large numbers of (dispersed) small users in rural areas presents more of a challenge.[27] Hence government influence over rural groundwater use is generally much weaker than it is for IDs, where water is delivered in bulk under capped permits and then distributed to farmers (Shah *et al.*, 2004; Calow *et al.*, 2006).

What has been the experience of government agencies and village collectives with respect to rights-based groundwater management? In their review of agricultural water policy reforms, Lohmar *et al.* (2003) highlight a historical bias towards investment in and management of surface water. More recently though, they note growing interest in both the development and control of groundwater withdrawals. Through the 1980s, for example, they suggest that the monopolization of well drilling activity gave local WABs fairly comprehensive control over access to groundwater since most deep wells were sunk by drilling enterprises owned by WABs. Hence groundwater access and withdrawal rights were conferred by public agencies, with wells themselves then managed by (typically) village collectives on behalf of farmers. In more recent years, however, they note that an increase in private well drilling companies and competition among collectively owned drilling companies (by township or village) has weakened this form of control. A similar trend has also been highlighted by Calow *et al.* (2006) in the Bashang Region of northern Hebei where up to eight government departments have funded wells, often with no prior permitting approval from the relevant WAB (see Box 1). Indeed some WABs operate their own drilling companies as they are forced, or choose, to operate along commercial lines.

Reporting on progress with permitting, Foster *et al.* (2004) note that some WABs have experimented with permitting systems since the 1970s,[28] but that strong legislative support was only provided in 1993 (see above). However, most authors conclude that in rural areas, implementation has been sluggish, unrelated to resource availability, or simply non-existent. For example, Foster *et al.* (2004), commenting on groundwater development on the North China Plain, note that permitting decisions have typically been made on an ad hoc basis, with no link between groundwater availability, the development of groundwater allocation plans and permitting.

The findings of recent field surveys in northern China support the findings above, and provide additional insights into the changing nature of groundwater access and withdrawal rights. Drawing on survey results from over 400 villages and six provinces, Wang *et al.* (2008) highlight the following:

- Fewer than 10% of the well owners interviewed had obtained a permit prior to drilling, despite the near universal (local) regulations requiring one.
- Infrastructure ownership (of wells and/or pumping equipment) has shifted dramatically from collective to private as well numbers have increased. In Hebei Province, for example, collective ownership of boreholes fell from 93% in the early 1980s to 56% in the in the late 1990s. At the same time, the share of private boreholes as a proportion of the total increased from 7% to 64%.
- Informal groundwater markets have emerged in many areas, mirroring similar trends in southeast Asia. Wang *et al.* (2008) note that in the 1980s, groundwater

markets were all but non-existent; by 2004, borehole operators in 44% of villages were selling water.

In conclusion, the authors state that in most of the villages surveyed, groundwater withdrawals are 'completely unregulated' and that, in the absence of government controls, farmers have invested in groundwater infrastructure and developed informal 'spot' markets to increase groundwater access and revenue.

Such shifts are significant for several reasons. Firstly, the growth in private investment and local perceptions of access and use that are increasingly private, irrespective of the legal status of groundwater, will undermine government efforts to implement abstraction permits. Secondly, and related to this, any decline in village/collective management of groundwater infrastructure increases the complexity of management as individual interests begin to dominate (Shah *et al.*, 2004). And finally, while groundwater markets increase access to irrigation, in the absence of any volumetrically defined abstraction rights, they will tend to accelerate groundwater withdrawals (Calow *et al.*, 2006).

Against this background, what opportunities are there for introducing—and monitoring—groundwater access and withdrawal rights? Again, government agencies are responding to the problem in a number of different ways, using pilot experience to ascertain what works best in different circumstances. First, we note that government agencies can and do take drastic action to control pumping in certain circumstances. In Wuwei Municipality in Gansu Province, for example, local authorities have sealed the wells of some farmers to stop pumping altogether in an effort to restore environmental assets and stabilize groundwater levels. The greatest restrictions are in Minqin County, where excess abstractions have resulted in the groundwater level dropping at an average rate of 0.65m per year and the drying up of the terminal lakes of the Shiyang River. This county is partly irrigated from surface water from the Shiyang River, but almost 90% of agricultural water was taken from groundwater in 2006 via small tube-wells irrigating about 100 mu per well. A comprehensive package of measures has been proposed to stabilize groundwater levels. This includes a reduction in the number of permitted wells by 3000 from 9519 to 6519 (32% of the original total) over the five-year period to 2010.

This will result in a reduction of the area of irrigated farmland from 1 020 000 to 625 300 mu (a reduction of 394 700 mu, or 39% of the original area). In addition the average irrigation quota for irrigated crops over the same five-year period will be reduced from 585 m^3/mu to 476 m^3/mu (a 19% reduction). The volume pumped from the remaining wells will also be reduced so that there will be a 70% overall reduction in groundwater use, but this is partly offset by an increase in surface water allocation from 139 million m^3 per year in 2006 to 265 million m^3 per year in 2010. A greater degree of control will also be imposed on active wells through volumetric discharge regulation achieved through the use of IC cards. The reduction in irrigated areas and quotas will be accompanied by the subsidized introduction of greenhouses on a large scale which will enable a more productive use of agricultural water and increase 'crop per drop'.

In the coastal area of Zhejiang Province, around 8300 km^2 of the coastal plain has been declared prohibited or restricted for groundwater abstraction because of pumping-induced land subsidence (WET, 2006; Wang *et al.*, 2009). And in some areas of the Bashang Plateau in northern Hebei (see Box 1), well drilling in counties facing severe groundwater drawdown has been prohibited under new regulations (WAMH, 2007). In view of the government's increasing concern with farmers' livelihoods and alleviating the peasants' burden, however, such moves may be exceptional.

Secondly, major project-based investment in registration and permitting has occurred in some over-exploited areas, supported by donor agencies and government partners. For example, the World Bank-funded Water Conservation Project on the North China Plain has invested heavily in county-level capacity building (for WABs) and farmer/field level education and technical change, focusing particularly on (a) technical, management and agronomic measures for reducing ET and generating 'real' savings; (b) groundwater monitoring; and (c) the monitoring and enforcement of abstraction quotas (Foster & Garduno, 2004). A recent evaluation (World Bank, 2007b) indicated that these measures had significantly raised agricultural production and farm incomes for over 300 000 households, while reducing groundwater overdraft and non-beneficial water losses.

Also in Hebei, the provincial WRD has established Integrated Water Saving Demonstration Projects in eight counties, combining similar water-saving measures (technical, agronomic, water scheduling/management) with groundwater management WUAs. Using IC card-reading technology—growing in popularity in China—farm households are assigned water quotas and water certificates (based on land holdings and crop water requirements) and can only irrigate with prepaid cards. WUAs then assume responsibility for the upkeep of completed systems, collect maintenance fees, organize rotations, monitor quotas and provide incentives and penalties for below and above quota abstraction, respectively (Calow *et al.*, 2006). In this way, government agencies set the rules of the game and provide technical support, but leave detailed monitoring and enforcement of household rights to farmers themselves. Whether such approaches can be scaled up to affect aquifer-wide groundwater conditions is debatable, however. In particular, the co-existence of village-based WUAs operating within a well quota and private entrepreneurs operating outside it opens the door to 'free-riding', with the conservation gains of the former simply captured by the later.

The Water Resources Demand Management Assistance Project (WRDMAP), funded by the UK Department for International Development (DFID), has advised on measures to improve groundwater management in Wuwei Municipality in Gansu Province. The large reduction in groundwater use needed to stabilize groundwater level conditions and thereby address to some extent environmental concerns was noted earlier. This will be achieved by revising well permits, issuing household water rights certificates (based on reduced norms for crop water requirements), installing IC card technology and increasing water fees. These restrictive measures will be accompanied by improvements to water delivery infrastructure, a smaller increase in surface water allocation, assistance with new crops and agricultural/irrigation techniques (including subsidies for greenhouses and drip irrigation). Institutional arrangements are also being strengthened through establishment of a management bureau at river basin level and WUAs at village level. Each village (or WUA) typically includes 20–50 boreholes which are managed by production groups (water user groups). The tasks of the village-level WUA include assistance to the water management station (WMS) in many of the new groundwater management responsibilities, including the issue of household water rights certificates, enforcement of permits and the collection of fees. These are onerous requirements and thus the WUAs are repaid part of the water resource fees collected in order to cover a small salary for directors and vice-directors and some administrative costs—in recognition of the role that WUAs play in water resources management. This formal process of paying staff from part of the newly-introduced water resources fee is important for ensuring that WUAs are effective and sustainable.

Household water rights certificates were introduced in 2007. These are prepared by the water management station and WUA and make allowance for all uses of water (domestic, agricultural and livestock). The precise sharing of responsibilities varies between counties and is being revised as experience is gained—the intention is generally that the WUA should take the primary role for entering correct household data, calculating the water rights on the basis of norms issued by the county WAB, and issuing the certificate on behalf of the WAB. The WMS provides a monitoring and quality assurance role as well as technical assistance. The certificates also allow for recording actual water use and thus serve a dual role of ensuring that the farmer receives water in accordance with their right and that abstractions are controlled in accordance with the norms. The certificate, however, does not yet mention the source of water, as the right is intended to be independent of the source. This causes some complexity in monitoring—particularly in areas which can receive both surface and groundwater. The certificate is a household certificate, held by the head of the household. This is significant as there is considerable off-farm employment and migration, and the (usually male) heads of household are often away.

IC cards were introduced on a pilot scale from 2006, and were widely installed in 2008. The intention is that all agricultural boreholes in Wuwei municipality should be fitted with IC card systems by 2010. These are installed by the WMS but maintenance is the responsibility of the WUA. In this case, the IC card is for the borehole rather than the household and limits the total abstraction to the sum of the household rights relating to that well. It should be noted that households often have land in more than one borehole command area, and this has to be taken account of by the WMS when charging the IC cards. Internal distribution within each borehole command area continues to be managed by the well operator or production group leader. This is a relatively simple task, but it will become increasingly contentious as norms are reduced and the WUA will need to be active in monitoring compliance with rights and resolving any conflicts arising from failure to observe them. The alternative which some farmers would prefer—individual IC cards corresponding directly to their water right, which they could use on any well—is considered too complex to administer in the short term, but may be introduced later.

The combination of rights certificates and IC cards has been introduced rapidly, and it is not surprising that there have been teething problems and a high workload for water management staff. The detailed working procedures are still being developed and modified in response to difficulties encountered. Well permits are now being re-issued by the Shiyang River Basin Management Bureau following a survey of all wells which verified location, depth, pump capacity, pump/well age and condition, area irrigated and other uses of water. This data has been entered into a geographical information system (GIS), together with some socio-economic and other data. Permits are currently issued for each well, although options for issuing a single permit for a WUA, to cover a group of wells, are being considered for the future.

Water resources fees for groundwater were introduced in 2007; these are intended to recover the costs of managing the resource (issuing and monitoring permits etc). Fees for excess water withdrawals are charged at a higher rate, but the fee is so small compared to the electricity charge that it does not act as a disincentive: control of water use thus relies on strict administrative enforcement of the water rights (via the use of IC cards and ensuring that pump operators comply with irrigation schedules agreed with the WMS). Fees are paid in advance and 'water tickets' are then issued. In theory these can then be traded (for up to three times the face value of the ticket) but this has not yet happened. In Minqin County, 5% of the water resources fee is returned to the WUA to cover part of their costs. Although water fees are prepaid, the electricity charges (which are the main cost incurred for groundwater irrigation) are paid in arrears and thus the burden on farmers is not excessive.

Finally, in the Bashang region of northern Hebei, we note that similar pilots have built on groundwater resource assessment, use/user surveys and risk mapping to determine which areas require high priority management of the kind described above. In addition to the targeting of WUA-based pilots, the assessment and mapping approach has also prompted Zhangjiakou City government to issue a number of local regulations intended to provide 'teeth' to the broad provisions of the 2002 Water Law. Hence, new regulations make it clear that county and city WABs need to approve any new well drilling across government departments in accordance with the groundwater maps described above. Perhaps more significantly, wider shifts in economic policy are also occurring, with an emphasis on livestock rather than (irrigated) cash crops. In view of the limited coverage of WUA-IC pilots, the growth in private investment in groundwater and the challenges of direct regulation, these changes may be more effective in relieving pressure on the resource base than narrow water resources management (Calow *et al.*, 2006).

Conclusions and Recommendations

In order to meet its growing demand for water with limited water resources, China needs to modernize and reform its system of water rights and establish effective implementation of such a system. A water rights system provides a transparent, rules-based system for allocating water within and between uses. This is particularly important at the sectoral level because irrigated agriculture is under growing pressure to release water to urban and industrial users. At the same time, farmers within IDs and in emerging groundwater economies need clearly defined rights so that they can make long term investments in agriculture, secure in the knowledge that their rights can be defended against competing claims except in exceptional circumstances.

This article has described the growth and importance of irrigation development in China, firstly in terms of the expansion of surface water irrigation led by the state, and secondly in terms of the more recent acceleration of groundwater irrigation, led increasingly by individual farmers. Key management challenges and changing policy priorities have been outlined, highlighting the growing emphasis on water conservation and IWRM under the new Water Law and the 11^{th} Five-Year Plan. The article then examined the basis for rights definition and allocation planning under the Law, looking in detail at how formal rights are allocated to agricultural users under basin allocation plans in both surface and groundwater contexts. Finally, the article has described implementation experience, firstly in terms of rights allocation to and within IDs, and secondly in terms of groundwater access and withdrawal rights.

Before looking at specific recommendations, some general observations are made. First, it is clear that China's quarter-century record of economic dynamism has been built on a willingness to experiment with new reforms in a pragmatic and flexible way. This is also apparent with water reform, as reference to China's many pilot projects in this paper has highlighted. Secondly, it is important to recognize a diversity of different water rights when discussing water resources management, looking beyond formal, state-issued authorizations to informal entitlements brokered by local organizations. At a local level, rights are embedded in contracting arrangements within IDs, in the collective property rights of village-managed groundwater systems, and in the allocation of household abstraction quotas under emerging groundwater-based WUAs. They may work well in managing local claims and obligations, especially where formal rights cannot easily be monitored and enforced. Finally, while this article has drawn heavily on experience from northern China, the challenges of water resources management in the wetter south should not be under-estimated. Here too, growing demand for water raises similar (albeit less pressing) questions about rights allocation, and the recommendations outlined below should be viewed in a national rather than regional context.

Drawing on the review of Chinese experience in this chapter, but also on wider international experience in rights reform, the following recommendations are offered.

Ensure an integrated and consistent approach to rights definition and allocation. Arguably the most detailed and robust systems have developed in those regions where water is most scarce, particularly in the north of China. The process of rights allocation within the Yellow River described in this paper demonstrates how integrated planning between different levels, sectors and users can occur, such that the water entitlement of a farmer within an ID is linked to the rights held by the district as a whole, and to each region's share of the available water from the Yellow River. Similar systems should be introduced in those basins where rights-based management has not yet been developed or implemented, including those in the south of the country.

Adopt water resource allocation plans as the basis for defining and allocating water rights, including the permits of IDs. The Yellow River case study also demonstrates how allocation plans should be developed, at basin and regional levels, as a basis for allocating water within a basin. Hence, in the Yellow River Basin, the plans clearly identify the water available for abstraction by IDs and other major users under variable resource conditions, and set capped permits that are strictly monitored and enforced. Similarly, allocation plans should specify groundwater allocations based on estimates of clearly understood aquifer safe yield as a basis for permitting and other management efforts (see below). In many basins, however, information on groundwater conditions remains limited, there is little or no connection between allocation planning and permitting, and permits (if issued at all) are often granted on an ad hoc basis.

Ensure that allocation plans adopt consistent terminology and planning processes with respect to consumptive and non-consumptive uses. In the south of China, the permits issued to IDs often prescribe an abstraction volume. In the drier north, a consumption volume with end-of-system return flows may be specified. Where practical, a distinction should be made between consumptive and non-consumptive use so that return flow accounting informs the overall allocation plan and issue of downstream rights. In this respect, water conservation and transfer programmes targeted at the agricultural sector require careful design. In an ID where irrigation returns provide useful aquifer recharge, for example, allowing irrigators (or an agency) to sell or lease rights defined as diversions may severely affect the rights of downstream users (see below).

Explore opportunities for providing certainty and security for holders of agricultural water rights granted by the state. The process for granting water rights, and in particular for allocating water to IDs on an annual basis, should be clear and consistent so that ID agencies—and the farmers within them—know when water will be available, how much water they will get and for how long they will get it.

Strengthen the claims of farmers within IDs through user-group contracting, the allocation of water certificates and increased involvement in local decision-making. Within IDs, WUAs and contractors also have an important role to play in ensuring that farmers receive timely information and can enforce their entitlements. Management reforms that increase participation in and the accountability of WUAs, and that support transparent and incentivized contracting arrangements, therefore play an important role in strengthening farmers' water rights. WUAs have been introduced rapidly over much of the country, particularly the north, but not all have been as effective as the initial pilot associations. Further measures to support and strengthen these WUAs, particularly for groundwater management, are needed if they are to become sustainable local organizations.

Explore opportunities for water trading but recognize its limitations. The sale or lease of agricultural water rights can raise the overall productivity of and returns to water, and can generate significant economic benefits once certain preconditions are in place. Establishing clear, enforceable rights, and then developing effective markets that work in the public interest, is a major challenge. Clear criteria for approving transfers and for predicting (and addressing) third party impacts are required for larger-scale, regional and/or inter-sectoral transfers. The growth of groundwater markets has been farmer led, with no volumetric caps on total withdrawals. Such markets can increase access to water and expand irrigation, but are likely to increase overall abstraction and accelerate overdraft in vulnerable areas.

Recognize the importance of groundwater irrigation in water resources planning and management. Groundwater development has played a significant role in increasing agricultural production, raising farm incomes and supporting rural development, particularly in the north of China. Yet its contribution to livelihood support, and the need for proactive management, has gone largely unrecognized by a water bureaucracy that often focuses on surface water engineering. The result, in many areas, has been explosive and sometimes unsustainable development, patterns of groundwater abstraction that are very difficult to regulate (particularly where private interests are entrenched), and allocation licensing that, if present, is unrelated to resource availability.

The starting point for considering groundwater management options is an understanding of patterns of use, and of services that need to be protected and that are feasible. 'Thick and deep' approaches to groundwater management, based on well permitting and volumetric licensing, may be difficult to apply across the large aquifers at risk in many rural areas of northern China. There are exceptions, of course, but these have typically involved either major project investment (difficult to scale up) or a reaction to emblematic events (isolated and infrequent). In this context, management approaches based on intensive, rights-based regulation by government agencies may be best directed at protecting 'strategic' aquifers where domestic use is threatened, or where reserve supplies may be needed to protect against shortages in extreme drought conditions. These may include deeper, confined aquifers that store potable water and have not yet been tapped by irrigators. In other areas, 'thinner' approaches may be more appropriate: support for groundwater management WUAs that allocate household quotas through IC equipment, for example, or the licensing of drilling companies rather than abstractors. Where private rights are now firmly entrenched, however, conventional approaches predicated on hydraulic control and regulation may offer little leverage. In these circumstances, government effort might be better directed at influencing wider economic incentives, in particular, providing incentives for less water-intensive cropping or, conceivably, supporting shifts into the rural non-farm economy.

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Notes

1. Using China's standard of defining poverty, i.e. income below $0.2 per person per day at the current exchange rate, or less than $0.6–0.7 at purchasing power parity (PPP). Note that China's poverty line is lower than that used by the World Bank to measure poverty in other countries ($1 per day at PPP).
2. The total environmental damage costs of air and water pollution were estimated at 5.8% of GDP (World Bank, 2007a).
3. Northern China is generally referred to as the area north of the Yangtze River. In terms of water availability, the North China Plain (or 3H Basin) has only about one-third the national average and about half the per capita water availability specified by the UN as the standard for maintaining socio-economic and environmental development.
4. Spence (1999) reports that during a three-month period between late 1957 and the end of January 1958, the State mobilized 100 million peasants to create a functioning irrigation system for 7.8 million hectares of land. Bramall (2000) reports that the proportion of irrigated land rose from 20% in 1952 to 50% in 1978.
5. Mandatory targets governed sown areas, yields, levels of input applications, planting techniques and other factors on a crop-by-crop basis. After 1978, mandatory targets were replaced by 'guidance planning' and market allocation (Ash, 1993).
6. De-collectivization and the re-introduction of household farming led to uncertainty about who should own and manage irrigation infrastructure and contribute to maintenance, especially as local government was reluctant to take charge of (and therefore subsidize) irrigation projects. Water charging—at a very low level—was only initiated in 1980. Hitherto, only a few larger and older IDs charged nominal fees; in most schemes, farmers paid no charges but were expected to contribute labour for construction and maintenance (Stone, 1993).
7. MWR (2006b) indicates that medium-sized IDs of over 10 000 mu (667 ha) and large IDs of over 300 000 mu (20 000 ha) account for 72% of the effective irrigated area.
8. According to official estimates, the number of wells in all of China was roughly 150 000 in 1965. By the late 1970s there were more than 2.3 million, and by 2003 the number had risen to around 4.7 million (reported in Wang *et al.*, 2007b).
9. Government abolition of local taxes and levies on farmers by village and township leaders may also undermine collective investment in groundwater infrastructure and indirectly encourage private development.
10. In practice the irrigated/rain-fed distinction is uncertain because of changing climatic conditions and irrigation needs from different sources.
11. MWR, 2006b. In reality the surface water/groundwater partition is also uncertain because of (a) the significance of informal, unmonitored groundwater development; and (b) the fact that groundwater demand will vary with surface water availability and climatic conditions, particularly in those areas that rely on groundwater as a supplemental or buffer source.
12. Revisions were required to address the growing problems of water scarcity and pollution that had arisen in the 1980s and 1990s. The 2002 Law makes water resource conservation a general principle in all relevant areas, and the subject of 17 separate articles (Wouters *et al.*, 2004).
13. The Chinese government maintains an unwritten policy of ensuring roughly 95% self-sufficiency in grains to ensure an adequate supply of affordable food. Agricultural trade broadly reflects comparative advantage, with sharp rises in imports of land intensive oil crops rather than wheat, rice or maize (OECD, 2005).

14. Since 2000, the government has attempted to reduce the 'peasant burden' by phasing out a range of government taxes, township and village levies and miscellaneous fees. In 2004, the government announced the phasing out of the Agricultural Tax over a period of five years (OECD, 2005).
15. According to the Ministry of Water Resources (MWR, 2006a), the 'water saving' irrigated area now comprises 34.5% of the total irrigated area.
16. The food price rises currently being experienced in China are generally attributed to rising demand, poor weather and outbreaks of livestock disease. Most commentators agree that the current global spike in food prices has little to do with China since the country continues to be largely self-sufficient in grain (Wiggins, 2008).
17. Only in 1998 were responsibilities for groundwater monitoring and management transferred to MWR from the Ministry of Mines (now the Ministry Land Resources—MLR) and the Ministry of Construction (in urban areas). However, most groundwater data and knowledge is still found within the hydrogeological branches of the MLR rather than with the MWR and its subordinate Water Affairs Bureaus (Foster *et al.*, 2004).
18. Under the 2002 Law, all water resources are owned by the state. Although state ownership is a cardinal principle of socialist legality, historically it has not led to effective control. This reflects, in part, China's civil law, allowing subordinate units of government to develop relatively firm entitlements and over-use resources (Wouters *et al.*, 2004).
19. River basin conservancy commissions have been established in six key river basins, including the Yellow River.
20. The conversion of Water Resource Bureaus to Water Affairs Bureaus began in Shenzhen in 1991, and has led to the consolidation of water resources development, management, flood control and rural-urban water supply under one roof (Shah *et al.*, 2004).
21. In practice, annual regulation plans are not prepared for many rivers, particularly in southern China where water resources are more abundant.
22. With certain exemptions, for example for stock and domestic purposes in rural areas, and rural collectives taking water from their own works.
23. Under the 1988 Water Law the state was required to adopt a permit system to regulate direct withdrawals from aquifers, rivers and lakes. In September 1993, the state also issued Implementation Procedures for the Water Drawing Permit System, outlining the scope and implementation measures for the permit system.
24. Permit No. 1 for Hangjin ID allocates 410 million m^3 to the district, including a mandatory return flow of 35 million m^3 per year. Permit Nos. 2 and 3 for Hetao ID allocate a much larger volume of 4.82 billion m^3.
25. Hence membership of the WUA, conferred through village registration and land ownership in the ID, provides farmers with rights to an irrigation service, subject to pre-payment, with accountability provided ultimately through voting rights. However, individual farmers only have an indirect role in ensuring the WUA does not lose any contractual water rights granted to it.
26. This assumes that channel leakage was not being used to maintain environmental assets or provide usable recharge to groundwater users. In many closed basins, this assumption may not be valid (FAO, 2004; Perry, 2007).
27. A typical groundwater district in the US or Australia might include one thousand farmers. In an area of comparable size in China, there may be 100 000 farmers, each withdrawing small volumes of water (Shah *et al.*, 2003).
28. Permits for well drilling can serve to check the numbers of groundwater users as well as the location and spacing of wells. However, abstraction licenses that (ideally) define variable shares of aquifer safe yield are required to control total groundwater withdrawals.

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