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A Sustainable Agro-ecological Solution to Water Shortage in the North China Plain (Huabei Plain)

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ABSTRACT *A highly seasonal rainfall pattern in the agriculturally productive region of Huabei Plain has been widely considered in China as a handicap to maximizing agricultural production. Enhancing this perception is the traditional policy of achieving provincial or regional self-sufficiency in grain production, which underlies China's production quotas. The Chinese government has decided to overcome this perceived handicap in order to meet the increasing water demands of urban populations and to achieving its grain quotas by constructing aqueducts to transport about 14×10^9 m^3 of water from the Dan Jiang Reservoir into the Huabei Plain. However, this engineering construction solution threatens the long-term market competitiveness of the region by driving up the cost of water relative to the value of the product, by taking too long to complete and by being unproven in its effectiveness. This solution also threatens the existing ecosystem by interfering with the natural hydrology, and it risks exacerbating the ongoing groundwater overdrafts that are contributing to the formation of numerous sinkholes and ground surface cracks in the region, as well as to the intrusion of sea water. A more certain, ecologically sound solution can be found in alternative agricultural practices and cropping systems. Reducing the winter wheat production by a relatively small acreage, combined with the increased use of water-saving irrigation systems, can more than replace the effectively usable 10×10^9 m^3 of water that the engineering construction project would transport via aqueducts. The recommended alternative cropping system would solve the water shortage problem immediately. This alternative would enable the government to allocate funds where they are more needed, such as to the clean-up of extensively polluted rivers and to ecological restoration, which bears on the sustainability of agriculture and food supply in China.*

Introduction

Administratively, Huabei Plain is a region of north-east China, including Hebei, Henan, Shanxi and Shandong provinces, and the cities of Beijing and Tianjing. It is the major part of the famous Huang-huai-hai (HHH) Plain (see Figure 1).

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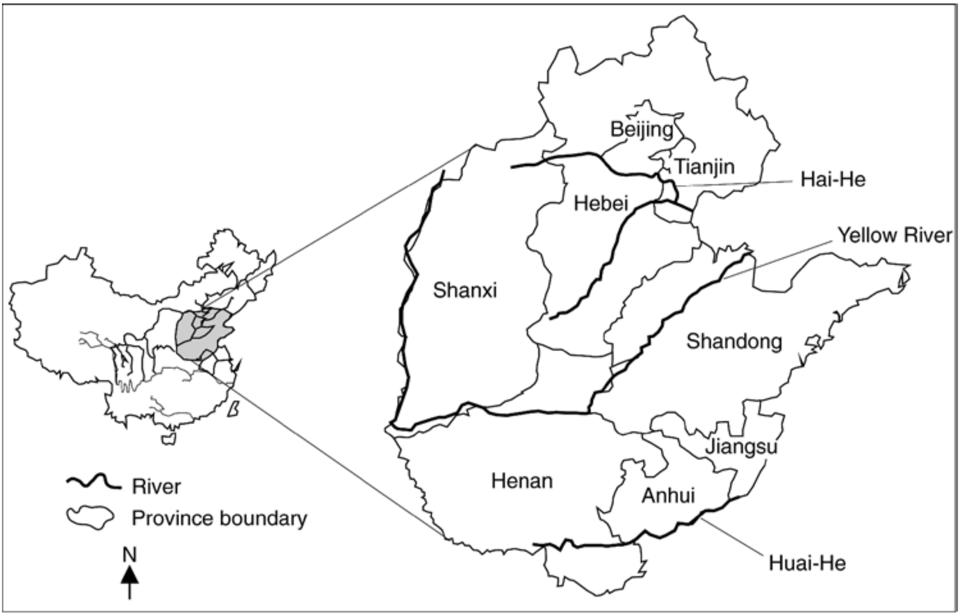

Figure 1. Main river systems in Huabei Plain, China.

This is the largest floodplain and is also the largest agricultural zone in China. Huabei Plain is the most prominent region in Chinese history (economically, politically and culturally) and is also one of the most important regions for current economic development. It contains 24% of the nation's population, 22% of the gross domestic product, 26% of the cultivated land, 30% of the irrigated land and 24% of the total grain production. Table 1 shows that Huabei Plain produces 52% of the wheat and 33% of the maize production in China. These values indicate that this region is of great importance to Chinese agriculture.

Table 1. Wheat and maize production in Huabei Plain

	Winter wheat			Maize		
Location	Area (10^3 ha)	Production (10^4 tonnes)	Yield (tonnes/ha)	Area (10^3 ha)	Production (10^4 tonnes)	Yield (tonnes/ha)
Beijing	171.3	96.4	5.6	206.3	118.9	5.8
Tianjing	151.1	77.4	5.1	151.2	65.5	4.3
Hebei	2 720.7	1 330.7	4.9	2 425.9	1 009.5	4.2
Shanxi	951.2	348.6	3.7	822.8	350.1	4.3
Shandong	4 037.6	2 241.3	5.6	2 626.8	1 106.0	4.2
Henan	4 927.3	2 372.4	4.8	1 952.4	807.7	4.1
Huabei Plain total	12 959.2	6 466.8	5.0	8 185.4	3 457.7	4.2
China	30 057.0	12 328.9	4.1	23 775.0	10 430.9	4.4
Huabei Plain as percentage of China	43.1	52.5	121.7	34.4	33.1	96.3

Source: Chinese Statistics Yearbook (1998).

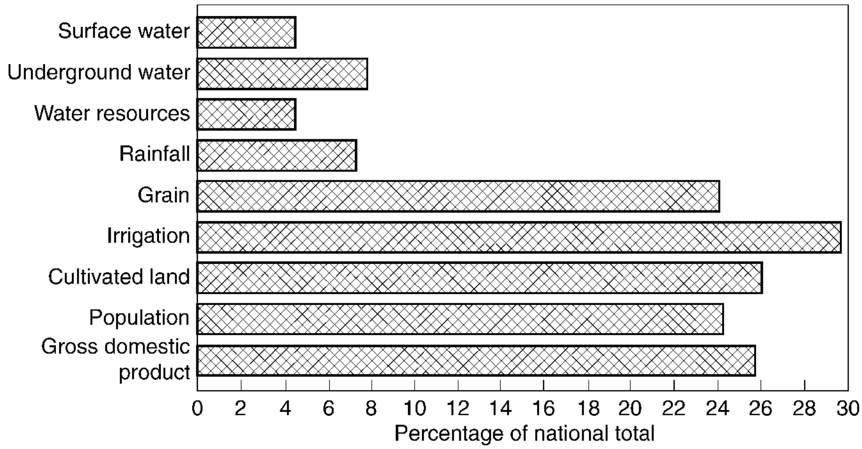

Figure 2. Economics and water resources in Huabei Plain.

However, Huabei Plain lacks water resources. Average rainfall is about 7.2%, surface water is about 3.3%, underground water is about 7.6% and total water resources are about 4.2% of the nation's total amounts (*Chinese Statistics Yearbook*, 1998; Chen *et al.*, 1999). Thus, water availability is substantially and disproportionately lower than the economic values of the region (Figure 2). As a result, the water shortage problem in Huabei Plain is the most serious in China, considering the economic contribution relative to the available water resources.

In this paper, we analyse the water problems in Huabei Plain, and recommend an agro-ecological solution for reasonable utilization of water resources in north China. This recommendation will protect China's hydrological system and is consistent with principles of sustainable development of agriculture.

Wheat and Maize Cropping Systems of Huabei Plain

Huabei Plain has a semi-humid climate with rains mainly in the summer. Light and heat are ample for agriculture. The annual average daylight is 2100–2800 hours, which is the highest for east China. The region has 188–225 no-frost days and the cumulative temperature above 0°C is between 4200°C and 5500°C. The light and temperature conditions support a 2-year, three-harvest rotation system, but rainfall is insufficient and ranges between 480 mm and 1050 mm, with the corresponding maximum evaporation range between 880 mm and 1025 mm. Except for the southern part of the plain, evaporation tends to be larger than the rainfall. The ratio of evaporation to rainfall amount, or the degree of dryness, ranges between 0.98 and 1.83 for the plain, which can be described as mainly semi-humid, a category in which the degree of dryness ranges between 1.0 and 1.5 (Department of Water and Electricity, 1987). Although rainfall in Huabei Plain is the limiting resource, compared with the available light and heat, it is sufficient to satisfy the need for one season's cropping system. Actually, the rainfall pattern in Huabei Plain favours crop production, because concentrated periods of rainfall and heat are coincident.

Huabei Plain's rainfall pattern is highly seasonal. Summer rainfall amounts to 350–550 mm, which is 50–75% of the annual rainfall. Winter rainfall accounts for only 2–8% of annual rainfall. Annual rainfall decreases progressively from south

Table 2. Seasonal and growth period rainfall (mm) and percentage of the yearly rainfall (in parentheses) in three locations in Huabei Plain

	Beijing (north)	Shongchu (middle)	Hooyang (south)
Year (January–December)	644.3 (100)	711.8 (100)	889.2 (100)
Winter (December–February)	13.0 (2)	42.3 (6)	71.7 (8)
Spring (March–May)	61.1 (9)	131.0 (18)	212.3 (24)
Summer (June–August)	482.6 (75)	398.8 (56)	451.6 (51)
Autumn (September–November)	87.6 (14)	139.7 (20)	153.6 (17)
Maize season (April–October)	616.1 (96)	617.8 (87)	732.3 (82)
Wheat season (October–May)	104.7 (16)	232.4 (33)	360.4 (41)

Source: National Ministry of Water Resources (1998).

to north (from 889 mm to 644 mm a year), but the degree of seasonal concentration of the rainfall increases from south to north (Table 2). For example, the summer rainfall in Beijing (northern part of the plain) accounts for 75% of the annual rainfall, but the comparable figure for Hooyang in the southern part of the plain is only 51% (Table 2). Basically, Huabei Plain has either wet or dry seasons. In order to fully utilize the other natural resources—light, heat and soil—for agricultural production, irrigation is applied intensively and extensively in the region (Hsu & Wu, 1989; Chen & Xia, 1999; Feng *et al.*, 1999).

The problem of overirrigation as a cause of water shortage is illustrated by comparing maize, which is grown during summer, and wheat, which is grown during winter. We shall analyse the potential productivity that can be supplied by light and heat, compared with that which can be supplied by rainfall. For example, in the less but more concentrated rainfall areas of the north-east and central-west regions of the plain, the ratio of potential rainfall to potential heat and light is above 60% for spring/summer maize, but $<50\%$ for winter wheat. This discrepancy is gradually reduced moving toward the southern part of the region, where rainfall is greater and also more evenly distributed through the year (i.e. less concentrated during summer).

Water-saving irrigation systems can correct the unevenness of rainfall distribution between seasons, but the amount of irrigation should not exceed the available rainfall amount in the same region, otherwise the region will face an overdraft problem. China has made much progress in developing the irrigation systems and has explored all possibilities within its economic and technical constraints. However, China faces a fundamental question: that is, should agriculture be considered as a part of the total ecosystem, co-existing harmoniously, or should the natural system be modified to fit the needs of agriculture?

Water Quantity and Quality in Huabei Plain

Because of population growth and limited accessibility to the markets, regional self-sufficiency until recently was the principal guiding policy for agricultural production and development. Demand for wheat, a main staple and a quality food in north China, has increased. As a result, the extended cultivation of winter wheat to meet self-sufficiency has become a necessary practice. The water demand of winter wheat is high, and the growing season largely overlaps with the dry period of Huabei Plain. Yields from dry land cultivation are low, and irrigation becomes a prerequisite for winter wheat production.

In the last 50 years, Huabei Plain has become one of the most developed areas for irrigation in China, which has resulted in significant yield improvements. Shanxi and Hebei, the driest provinces in the region, have increased their combined area of irrigation from 1×10^6 ha in 1949 to 5.38×10^6 ha in 1997, which is a 5.3-fold increase and indicates an annual growth rate of 3.5% (*Chinese Statistics Yearbook,* 1998; National Ministry of Water Resources, 1998). Fifty million hectares were irrigated in Huabei Plain in 1997 (*Chinese Statistics Yearbook,* 1998). This irrigated area comprised about 62% of the total cultivated land, which was the highest proportion in the nation, the national average being 54%. China used 525×10^9 m^3 of water in 1993, 19% of the total water resources in China. In 1995 the total water supplied for use in Huabei Plain was 82×10^9 m^3, 70% of the total water resources of 117×10^9 m^3 in the plain. Of the 82×10^9 m^3 of water used in Huabei Plain, 56% (46×10^9 m^3) came from underground water resources. This amount was 27% more than the surface water use, which was 36×10^9 m^3 (*Chinese Statistics Yearbook,* 1998). In fact, this level of groundwater use was 73% of the total underground resources, which depletes the groundwater table by 1–3 m per year. This rate of depletion has continued for at least the last 30 years, which is one of the most consistent and highest depletions of water anywhere in the world.

Actually, agricultural water use in this region reached its maximum during the end of the 1970s. In recent years, industrial and urban water uses have gained a higher national priority, replacing the old priority of agricultural use (Horsley, 1994). Water consumption in the HHH watershed in 1993 was 107.3% of the amount in 1980. Industry usage increased by 165.9%, urban usage increased by 231.4% and agricultural usage did not increase. Even so, agriculture still used the largest amount of water. For instance, in 1993 urban water use was 3.7%, industry use was 12.9% and rural use was 83.3%. Of this rural use, agricultural irrigation used 78.7%. Because water irrigation use is more than two-thirds of the water supplied, the problem of water shortages in Huabei Plain is closely related to water use in agriculture (Zhu, 2000).

Irrigation is particularly intensive for wheat production in the region, where 86% of the wheat production area is irrigated. Water consumption for winter wheat is estimated as 5490 m^3/ha (Xue, 1998). The effective rainfall during the growing season is 2031 m^3 in Huabei Plain, which is only 37% of the water demand. Therefore, winter wheat requires an additional 3459 m^3/ha. The total volume of water used for irrigating the winter wheat in this 13×10^6 ha area amounts to 45×10^9 m^3, which is 81% of the 55×10^9 m^3 of irrigation water in the region. In contrast, urban and industrial water use together totals 18×10^9 m^3, which is less than 40% of the water used for wheat production alone. It is clear that the reason for the lack of water in Huabei Plain is primarily excessive water use for agriculture, and specifically for winter wheat production. In fact, the amount of irrigation water used for wheat production is almost equivalent to the total amount of the ground water used for the entire region.

The excessive use of water in Huabei Plain has serious consequences for the balance of the hydrological system in the region, and causes subsidence. Because of the overdraft of groundwater, China has 56 known large sinkholes occurring at aquifers. Huabei Plain alone has more than 30 of them. Water depletion at the centre of each sinkhole averages about 2–3 m per year. Because of the subsidence

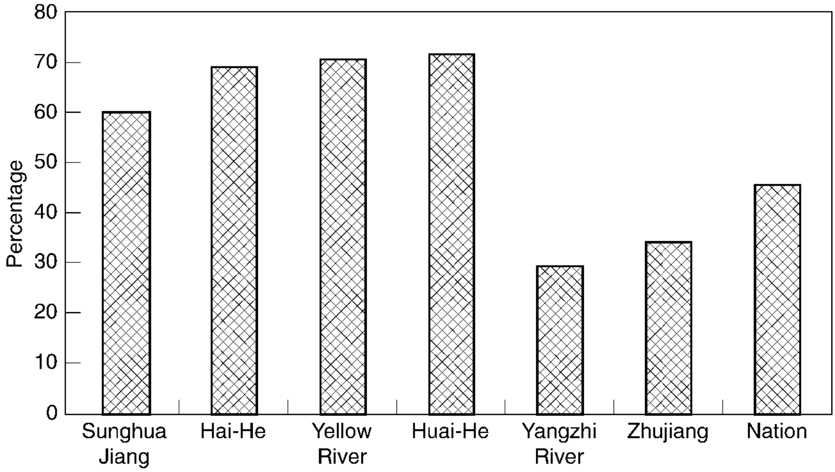

Figure 3. Percentage of pollution along the length of China's main rivers.

induced by this groundwater overdraft, Hebei Plain has formed more than 200 ground surface cracks, affecting 35 counties. Because of groundwater depletion, sea water encroaches inland at more than 70 locations in Hebei, Shandong and Liaoning provinces (Liaoning is outside Huabei Plain). The total area affected by the seawater intrusion in these provinces is 1433 km^2, and on average it intrudes inland another 5–8 km. The greatest annual extent of intrusion was 12 km, affecting more than 1 million people, as well as industry and agricultural production.

The lower reach of the Yellow River has dried up 19 times over the last 25 years (*Chinese Statistics Yearbook*, 1998). During this period, up to 64% of the river has dried up and the longest dry period spanned over 200 days (in 1997), extending 683 km. It seriously affected the livelihood of the people who lived on both sides of the river, and negatively affected the river's ecology. The most damaging effect, however, has been that of pollution. According to a recent evaluation (Liu & He, 1998), 46% of the total length of all rivers in China is polluted. Among them, 72% of Huai-He River, 71% of Yellow River and 69% of Hai-He River is polluted (Figure 3).

Water Demand and Water Diversion from South China to Huabei Plain

Because of the great need to supply adequate food to the massive Chinese population, it is understandable that self-sufficiency has been the key policy goal for administrative jurisdictions and regions. Since 1983 Huabei Plain has achieved self-sufficiency in grain production. The total production for that year was 63×10^6 tonnes and the per capita average was 380 kg. In 1997 the total grain production reached 118×10^6 tonnes, which was 188% of the 1983 figure. Per capita grain production was 396 kg, 104% of the 1983 figure. The wheat cultivation area was 45% of the total cultivated area in 1980, and increased to 53% in 1997. Many experts and scientists in China have estimated that in 2030, when the population reaches a plateau, Huabei Plain will experience a water shortage of 16×10^9 m^3, assuming the policy of self-sufficiency continues. This amount is equivalent to the combined urban and industrial water usage at the present time.

The approach to solving the water shortage problem in north China adopted by the government is to move water from south to north by constructing three parallel aqueducts located in western, central and eastern parts of China. The government plans to construct the central aqueduct to send about 13×10^9–14×10^9 m^3 of water from Dan Jiang Reservoir to Huabei Plain. After evaporation and leaking of 30% of the water during the transfer process, this aqueduct is projected to send approximately 10×10^9 m^3 of water to Henan, Hebei, Tianjing and Beijing, of which 6.1×10^9 m^3 will be used mainly for urban and industrial needs, so the agricultural use of this diverted water will be rather limited.

One of the most important grain production areas in central China is Hanjiang watershed in Hubei province. After the Dan Jiang Reservoir water moves north, it will have a tremendous impact on agriculture, shipping and ecology along the middle and lower reaches of the Hanjiang watershed. The water flow of the central aqueduct will have to cross the flows of more than 200 tributaries of the Huai-He, Hai-He, Yellow and Yangzhi rivers. The upper reaches of these rivers are famous as storm and flood regions of China, bringing special challenges to the engineering of the aqueduct. The construction of this central aqueduct, which will be about 1300 km long, will inevitably alter the ecology on both sides of the aqueduct to a degree beyond quantification or prediction. This extremely long water diversion will also have a high economic cost (Figure 4). The water will certainly be expensive, which will bring a heavy economic burden to Huabei Plain and the Chinese government. China is expected to join the World

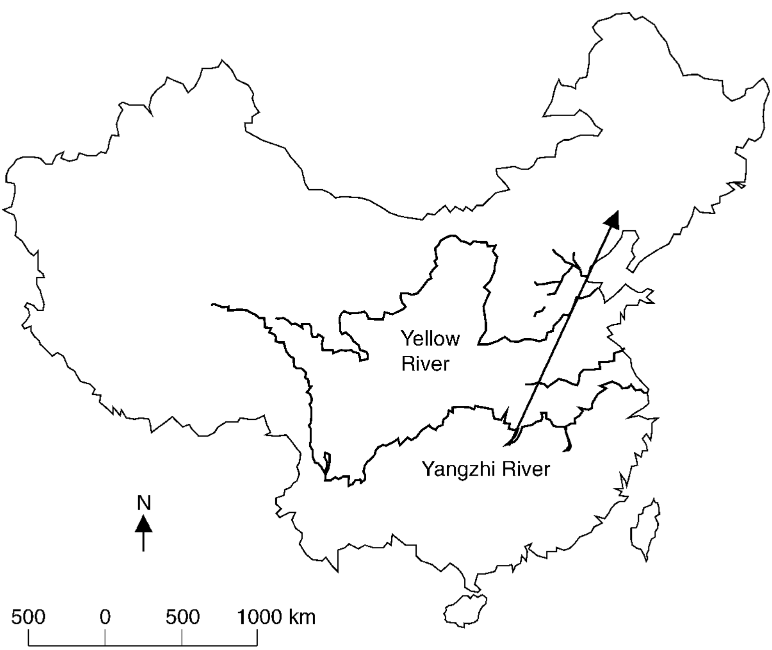

Figure 4. Water diversion (central aqueduct) project.

Trade Organization in the near future. The added cost of production will weaken Huabei Plain's competitiveness in both national and international markets. Regardless of the economic feasibility and ecological consequences of the proposed project, the construction itself will still take many years to complete before becoming operational.

The long-term benefits and risks cannot be projected reliably and need more time for assessment and observation. However, the water issue is so pressing and urgent that it cannot wait for long-term, unproven engineering construction solutions. The water transfer will do nothing to curb current irrigation malpractice, and will thus contribute less water for agricultural production than is projected by planners (Smil, 1991). From an ecological systems point of view, the sustainability and equilibrium of the ecosystem rely on the self-balancing and self-correction of internal mechanisms, rather than on the introduction of external factors.

Alternatives to Transporting Water to Huabei Plain

The spring and summer cropping system represented by maize, which is usually grown from April until October, coincides with the rainfall season in this region. The degree of coincidence (the percentage of total rainfall in the growing season) is stronger in areas of less rainfall, which tends to decrease from north to south, and is 95.6% in the north-east, 92.1% in the mid-east, 86.8% in the south-west and 80% in the south. For winter wheat, the growing period extends from October to May of the next year. The coincidence with rainfall tends to increase from north to south, and is 6.3%, 24.4%, 32.6% and 45%, respectively, for the above-mentioned areas within the region. Within the growing season, the ratio of effective rainfall to water demand is about 90% for maize and 37% for wheat.

The effective economic water demand for maize is 5370 m^3, which is about the same as for wheat (Xue *et al.*, 1998). However, the effective rainfall amount for maize is 4833 m^3, or 90% of the demand. Thus, the irrigation demand of wheat (3459 m^3) is 6 times the irrigation demand of maize. In addition, the ratio of yield to water use is about 7.86 kg/m^3 of irrigated water for maize, which is 5.4 times higher than the 1.44 kg/m^3 for wheat.

Historically, Huabei Plain was planted with crops suitable for the pattern of rainfall distribution, such as maize, peanuts, spring sorghum, summer soy beans, spring potatoes and other spring cereals. This planting regime was more ecologically balanced for a very long time. Only in limited areas where irrigation was practicable were cotton, wheat and even rice grown. For example, in 1949 spring crops occupied 81%, and autumn crops only 19%, of the total acreage of grain crops in Hebei province. Local farmers relied on their generations of experience to select these crops and to develop the corresponding cropping systems for their strong adaptability to the local environment. On the basis of these cropping systems, people in Huabei Plain developed unique cultural and dietary habits, which were relatively harmonious with the natural environment. Because of the economic and technological changes over the last several decades, irrigation areas have expanded and living standards have risen to a degree that may make impracticable and also discourage a return to traditional cultures and habits. However, it is important to re-establish a production system that is suitable for the natural environment.

In a mature marketing system the lack of water should be directly reflected by the cost of water and the increased cost of the product. This cost will serve as a mechanism to discourage inefficient water use and unnecessary water development projects. From an ecological economics point of view, the suitability of agricultural resource development depends on the type of cropping systems that will be best for the growing conditions. In the case of Huabei Plain, the most sustainable agricultural systems would be rainfall-dependent cropping systems instead of irrigation-dependent cropping systems. Yet current practices of cropping systems in China are based largely on the principles of self-sufficiency and maximum yields, which are not necessarily cost-effective.

The water problem originating from agriculture should be resolved through the restructuring of agricultural systems (see Smil, 1991). For example, the maize–wheat cropping system in Huabei Plain could be modified into an integrated livestock and cropping system. A policy change from grain self-sufficiency to water self-sufficiency in the region will be imperative for the long-term sustainability of Huabei Plain's agricultural productivity. The trend in the autumn cropping acreage of wheat increasing from being historically less than 20% of the region's area to 48% in 1997, needs to be re-evaluated.

Currently, the area of maize planting in Huabei Plain is 8.2×10^6 ha and that of wheat planting is 12.9×10^6 ha (Table 1). Lacking accurate data, we can only assume that all this maize acreage is intercropped with winter wheat and that at least 4.7×10^6 ha of wheat was planted outside the intercropping system. The irrigation amount for this 4.7×10^6 ha of wheat is about 16×10^9 m^3 of water. If only a portion of this acreage was changed to maize or pasture, or even left fallow, the water problem would be alleviated immediately. Data have shown that alfalfa produces 4.7 times more dry matter, and 7 times more protein, than does wheat on a per hectare basis (Smith, 1995). Preliminary data indicate that alfalfa can be harvested four to five times in north China, and can produce a dry matter yield 3–4 times higher than that of maize. There are plenty of alternatives to growing winter wheat on Huabei Plain, and some of these alternatives, such as locally developed integrated greenhouse systems, would be more profitable and, more importantly, more water-efficient.

The aqueduct project is designed to send 10×10^9 m^3 of water from Dan Jiang Reservoir to Huabei Plain. Since the irrigation water required for winter wheat is about 3459 m^3/ha, the same amount of water could be obtained by removing 3×10^6 ha of winter wheat, about 23% of the wheat acreage in Huabei Plain or 10% of the national wheat acreage.

Another way to save water is to adopt water-saving irrigation techniques, such as drip and sprinkler irrigation. Compared with flood irrigation, drip irrigation is 40–50% more water-efficient (Liu & Cheng, 1996). The average efficiency of irrigation water use in Huabei is about 48%, with every 1% of irrigation efficiency corresponding to 820×10^6 m^3 of water. Thus a 6% improvement in efficiency could save an equivalent 5×10^9 m^3 of water. Water-saving irrigation methods can resolve much of the water shortage problem of Hebei province (Liu & He, 1998; Li & Liang, 1999).

By both readjusting the cropping system and implementing water-saving techniques (e.g. reducing the wheat planting area by 11.5% and increasing irrigation efficiency by 6%, which can be implemented quickly), it is entirely possible to save the 10×10^9 m^3 of water planned to be redirected to Huabei Plain. It would be more profitable and more ecologically sound, and would promote the sustainability of agricultural systems in Huabei Plain.

Concluding Remarks

There have been many attempts to engineer solutions to perceived water shortage problems, but many of these attempts have generated unpredicted new problems (Leopold, 1994; Kondolf, 1997). For example, as seen elsewhere, diverting flow from the Yangtze River might deeply incise the stream bed downstream of the diversion, causing gully erosion and other problems. The diverted flows might carry heavy sediment loads north, thereby challenging the integrity of the aqueducts. Alterations to stream flows also devastate stream fauna (Moyle, 1986).

The origin of China's central water diversion project is Dan Jiang Reservoir. The first-phase construction of Dan Jiang Reservoir was completed in 1973. The normal water height is 157 m, and the reservoir contains 17×10^9 m^3 and inundates 745 km^2 (National Ministry of Water Resources, 1999). When the diversion project is completed, the water height will reach 170 m, and the inundated area will be 1050 km^2. The total water volume will be 29×10^9 m^3, which is about 50 times the size of California's Shasta Reservoir. The total length of the aqueduct will be about 1300 km, and will include an additional 40 constructed overflow holding ponds and 1851 structures and 97 branching aqueducts to supply water to the region. The aqueduct and its overflow ponds will permanently occupy 14 300 ha of previously cultivated land (Yen, 1999). Dan Jiang Reservoir will increase the area of storage by 305 000 ha. Thus, the total land converted from agricultural uses to water storage is estimated to be 319 300 ha, or 1.3% of the area of Huabei Plain currently cultivated. The estimated cost of the project is between ¥63 billion and ¥77 billion. Furthermore, the upstream watershed of the Dan Jiang Reservoir contributes 127×10^6 m^3 of polluted water flows from agricultural industries, cities and townships (Yen, 1999). This volume of pollution is expected to nearly double over the next 20 years.

Importing water to Huabei Plain also does nothing to address the indications of serious ecosystem degradation there. The land is subsiding, sinkholes and ground surface cracks are developing and sea water is encroaching. These trends are signs of groundwater overdraft, and they threaten to reduce the spatial extent of soil that can be considered arable. These trends are significant locally and internationally, because about 95% of human food comes from crops and livestock, and much of this food is produced on about 11% of the world's terrestrial surface area (Bridges & Van Baren, 1997). Therefore, by ignoring the overdraft of groundwater and the loss of soil in Huabei Plain, China could deplete its resource base to such an extent that further agricultural development would be impossible and its ability adequately to meet future food demand would be seriously compromised.

The water shortage problem in Huabei Plain is mainly caused by overcropping of winter wheat. Adjustment of the cropping systems in the region, combined with the adoption of water-saving irrigation methods, can resolve much of the region's water shortage problem. We suggest that an agricultural, rather than an engineering construction, solution is most appropriate for solving the water shortage problem in China's Huabei Plain.

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