Design Issues in Controlling Drought and Waterlogging/Salinity in Farmer-Managed Irrigation Systems on the North China Plain

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THE BASINS OF the Yellow, Huai, and Hai rivers in the North China Plain account for the greatest regional share of China's agricultural production. Encompassing 352,700 square kilometers, the North China Plain is the largest plain in China, making up about one-third of all of the nation's flatland. Its cultivated area of 18,265,000 hectares (ha) is one-sixth of the national total. Agricultural output from the Plain is significant. In 1983, total grain output was 70,770,000 tons, more than one-sixth of the national total, and cotton production was 2,686,000 tons, or more than half of all cotton produced in the country.

The North China Plain has a semi-humid monsoon climate, with drought and wind in the spring and early summer, followed by a hot, rainy season. Mean precipitation is about 500-1,000 millimeters (mm), decreasing from south to north, well below the potential average evaporation. Precipitation is seasonally concentrated and differences between precipitation and field-water consumption are below zero in most parts of the Plain. Rainfall meets only one-third of the total crop demand for water for winter wheat, which makes irrigation indispensable to agricultural production on the Plain.

The soil of the Plain is formed from the alluvium of the Yellow River. All the parent soil material is somewhat saline. With the Plain's flat topography, groundwater movement is almost entirely vertical. After the introduction of surface-water irrigation, an increase of groundwater recharge via canal and land seepage occurs. Thus, mean recharge becomes positive and the water table rises near to the surface in the absence of proper drainage. With an elevated groundwater table the soil's capillary action can carry saline groundwater into the cultivated layer where the salts remain after evaporation. Secondary salinization and waterlogging in the wet season can occur easily without an appropriate drainage system.

The state and farmers have made great efforts to increase agricultural production through irrigation on the North China Plain. There are 7,100 large, middle, and small reservoirs with a

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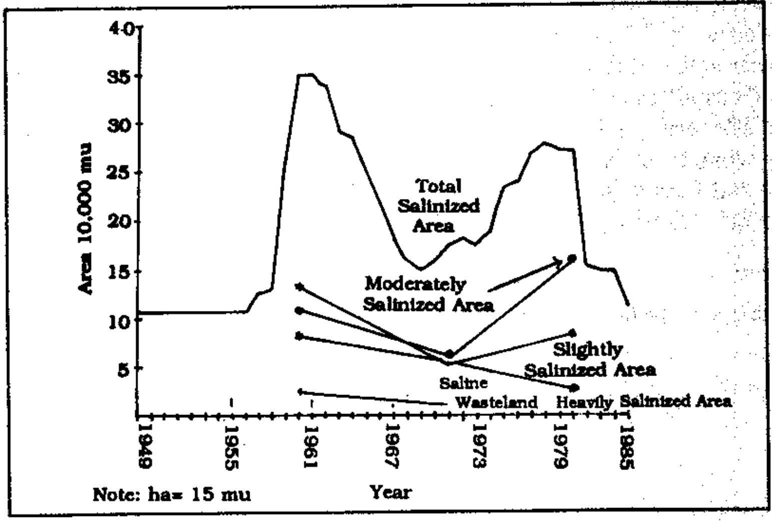
total storage capacity of about 52.5 cubic kilometers, controlling 50 percent of the natural recharge of the Yellow, Huai, and Hai rivers. One million four hundred thousand tube wells pump 60 percent of the groundwater recharge. In recent decades both surface and groundwater have been exploited on a significant scale. The total irrigated area in the North China Plain was roughly 10,000,000 ha, about 54 percent of the total cultivated area. Despite many efforts to use water effectively, agricultural production is still low. The average grain yield is only 3.23 tons per ha, which is 5-20 percent lower than the national average, and the low-yield area (less than 2.25 tons per ha) covered about one-third of the total cultivated area on the Plain in 1983. One of the primary reasons for the low yield in this area is that there is poor linkage between design, construction, and operation of water-conservancy facilities.

TRADE-OFF BETWEEN DROUGHT CONTROL AND WATERLOGGING/ SALINITY IN THE NORTH CHINA PLAIN

Efforts to increase the agricultural production of the North China Plain must take into consideration the design and construction of facilities which can provide protection against both drought conditions (lack of water) and waterlogging/salinity problems (too much water/accumulation of salts). The history of the North China Plain reveals a gradual learning process about the design of facilities for water control.

Despite the installation of many brick wells and ponds there was little evident change in irrigated area between 1949 and 1955 because the principal task for agricultural production during these years was alleviating drought conditions. The groundwater table and saline area were stable and low. The groundwater table was kept lower than the critical depth, so groundwater evaporation was considerably lower. Figure 1 shows the fluctuations in salinized area in Yucheng County between 1949 and 1985.

Figure 1. Salinized area in Yucheng County.



Generally speaking, drainage presents a major problem on the North China Plain. At the beginning of the 1950s there were no drainage ditches or culverts, and the rivers were choked with weeds, seriously impeding drainage. The Plain was under the continual threat of waterlogging. In large floods such as in 1937, over 60,000 ha (90 percent of the usable land) were submerged in Yucheng County. The drainage situation was aggravated in 1958 when the North China Plain began to divert and store irrigation water from the Huang He. The people soon found themselves faced with a rise in the water table. After the heavy flood of 1961 neither the surface water nor the groundwater could be drained promptly, causing severe waterlogging and secondary salinization of the soil. The saline area of Yucheng County increased from 8,000 to 23,000 ha, and virtually all of the grain crop was lost.

Thereafter, the people refocused their attention on the design of drainage works, especially for surface drainage although in so doing they not only failed to complete their original irrigation systems, but even destroyed some of the existing facilities. The consequences of this strategy were brought home with a major drought in 1968 when both the rivers and the wells dried up and there was no water for irrigation. Grain output again collapsed.

It was realized that a more balanced approach to controlling drought and waterlogging/salinization was needed. First, attention was given to designing and implementing a system which could handle both irrigation and drainage. Beginning in 1972 there was a rapid increase in irrigated area. However, the saline area also increased slowly between 1972 and 1975. After 1975 the people began to neglect the facilities used to prevent increased salinity. Some of the drainage canals were again allowed to fill with silt deposits, reducing the drainage capacity of the original design and bringing about a sharp increase in the saline area between 1976 and 1981. A net decline in saline farmland during the 1980s is primarily the result of a succession of dry years, and coexists with large salinity increases in some areas. Obviously, continued and increased use of interbasin surface water or successive years of heavy precipitation can reverse the county-wide trend. Monitoring of soil salinity and groundwater level, and the management of groundwater level are critical to sustain increased agricultural production.

DESIGN INNOVATIONS IN FARMER-MANAGED SYSTEMS[8] TO CONTROL DROUGHT AND WATERLOGGING/SALINITY

The realization that irrigation design needed comprehensive facilities for combatting drought, waterlogging, and salinity evolved gradually. An experimental district with an area of 130 square

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[8][Note: Mr. Ren Hongzun has used a different definition for farmer-managed irrigation systems from that used by other authors in this publication and at the International Workshop on Design Issues in Farmer-Managed Irrigation Systems. His use of the term farmer-managed irrigation systems in this paper actually refers to farmer participation in operation and maintenance of jointly managed irrigation systems. Workshop organizers.]

km, including 9,270 ha of farmland was established in Yucheng County in 1966. Inasmuch as 7,300 ha, or 80 percent of the farmland was subject to varying levels of salinity, and 87 percent of the farmland was under irrigation. The main purpose of establishing the experimental district was to explore ways of controlling drought, waterlogging, and salinity in the North China Plain.

The Yucheng Experimental District

The Yucheng Experimental District is surrounded on all sides by rivers: the Tuhai on the north, the Old Zhaoniu to the east, the New Zhaoniu to the west, and the New Shentun to the south. The Nanying storage gate was built on the Tuhai River north of the district. The Panzhuang main canal transporting water from the Huang He passes through the western part of the district. Based on the topographic situations, the district can be divided into three areas: 1) higher land with better drainage conditions, 2) depressions with poor drainage, and 3) higher land with poor drainage.

Components of Comprehensive Water Control

Comprehensive water control is a combination of design innovations for irrigation to alleviate drought conditions and for drainage systems to control waterlogging and salinity. Efforts to achieve an effective system for water control in the experimental district included the following components:

1) design and implementation of a drainage and irrigation system,
2) establishment of a network of wells to tap groundwater resources, and
3) consideration of agronomic and forestry factors.

Setting up a drainage and irrigation system. A six-level canal system was set up in 1972 using the Tuhai River as the principal natural channel. The Tuhai was widened from 30 meters (m) to 300 m, deepened from 3 m to 5 m, and straightened to carry a flow of 614 cubic meters per second. Three other natural channels, the Wei, the Chaoniu, and the Tuma rivers, are 4-5 m deep. The 14 branch canals are 3-3.5 m deep and about 2,000 m apart. The 80 subbranch canals are 2.5-3 m deep and 500-1,000 m apart. The 206 farm ditches are 1.5-2.5 m deep and 500 m apart. In addition, there are 3,660 field ditches with a depth of 1-1.5 m each, 100 m apart.

The system has two roles. First, in the flood season, it drains the surface water and some of the saline groundwater to help maintain a low groundwater level. This allows rainfall to infiltrate deeper into the soil and strengthen the role of precipitation in leaching out salts. Second, at other times, excess water from the Yellow River diversions can be stored for later use. The main channel stores water for half a year or more and the branch ditches hold water for two months or more. The objective is to keep the groundwater level below the critical depth where salts may be carried into the cultivated layer of soil. Experimental data estimate the critical level to be about 2 m for the fine sand soil in Yucheng County. Hence, when storing water in the canal, it is necessary to limit the tributary level on the gate to no less than 2.5 m from the surface. The storage capacity of the system is about 20,000,000 cubic meters (m^3). Water can be stored three times a year, providing a total storage capacity of about 67,000,000 m^3 including a capacity of 7,000,000 m^3 in 2,935 ponds scattered throughout the area.

Establishing a network of wells. There are abundant groundwater resources in the experimental district which can provide good quality water. The waterbearing strata consist principally of fine or medium sand and silt. The average depth of the groundwater level is about 0-0.5 m in depressions along the slopes. A network of 1,050 pump wells 50-100 m deep was established in the experimental district. The mean yield of each well is 60-80 cubic meters per hour. The network of wells functions as a water supply and lowers the groundwater table, decreasing the evaporation of salts at the surface.

Other agronomic and forestry measures. Hydraulic measures must combine agronomic and forestry measures as supplemental methods to control drought and waterlogging/salinity problems. Leveling of cultivated land has increased the efficiency of water application and leaching of salts. Improving soil fertility has changed the soil structure, increasing its porosity and moisture storage capacity to facilitate the downward movement of water and salts. Setting up a field-tree network has helped raise the relative humidity and lower average daily temperatures. The tree root systems also aid drainage and help reduce the water table.

Effects of the Water-Control Innovations in the Experimental District

Positive effects of the design and construction of the canal system in the experimental district for the control of water scarcity, excess water, and salts have already been observed. Farmers have had abundant water for irrigation. Waterlogging can be controlled when daily rainfall remains less than 200 mm. The groundwater table has been lowered to 2.5 m or more in depressions, and the salinity area has decreased from 7,333 ha in 1949 to 2,133 ha in 1984. Despite an increase in 1975-77 in the saline area, fluctuations have been less in this zone. Soil salinity was reduced from 0.19 percent to 0.12 percent. Grain yield increased from 1.6 tons per ha in 1975 to three tons per ha in 1979. Currently, yields are more than 7.5 tons per ha.

The total investment in the experimental district was about US$3,210,000 from 1966-79, including US$2,140,000 from state funds and US$1,070,000 of collective investment. Average cost per ha was US$344 of which US$315 was invested in digging canals and wells. According to an estimate made by the Chinese Academy of Agricultural Sciences, the average return on this investment in terms of income from increased production of grain and cotton is US$350,000 per year calculated on the basis of a production comparison at 1980 prices between the 1976-80 period and the pre-improvement period. The comprehensive measures implemented in the experimental district are an example of a successful investment experience in transforming low-productivity land.

INTERACTION OF DESIGN AND MANAGEMENT OF THE SYSTEM

In the past, China's irrigation projects have emphasized construction of physical facilities and neglected the water-management aspect. Many problems arose in water use and distribution resulting in underutilization of the capacity of the irrigation system. In order to improve the linkage between the design of the physical facility and the management of the water for more efficient, extensive use, the Production Responsibility System was introduced. Here, the basic technique used to improve water management is the manipulation of economic incentives. It is envisioned that in the future the state may give the responsibility for maintaining and renewing water projects to the local water-management organization to run as a business that can recoup its own costs. However, at present, the state continues to provide some financial assistance.

There are three fundamental parts of economic reform in water management: 1) Individual income should be related to individual work performance rather than to communal obligations and consumption. This is known as Post-Responsibility. 2) Economic contract responsibility or the management of water resources as a business, transfers the sole responsibility for profits and losses to the managers. 3) Development of a diversified economy to increase income is the third aspect of economic reform related to water management.

Instituting Post-Responsibility

The purpose of the concept of having the individual's income related to his work performance is to institute a sense of responsibility for good job performance. Each staff member and worker is responsible for carrying out the clearly specified duties of his or her position. At fixed intervals performance is evaluated and he or she given differentiated compensation based on economic criteria. For example, the water-management office of the Wei Shan Irrigation District located north of the Yellow River in Liaocheng Prefecture of Shangdong Province distributes water based on the area irrigated or the volume of water used and gives the lower reaches priority in water use to ensure equitable water distribution. Water-measurement stations were set up and people assigned to measure the amount of water used. The income of the staff is related to the area irrigated and collection of the water fee. Some people were assigned to improve or build 300 delivery and diversion aqueducts. Their income and rewards were based upon the degree to which they completed the assignment. Also, households or individual farmers were given contracts to maintain banks, trees, and small structures for ten years. Seventy percent of the total income from the sale of the trees and other agricultural products belonging to the households or individuals is kept by the individual. Thirty percent of the income is given to the water-management organization.

Through the implementation of the post-responsibility system the following benefits resulted:

1. The gross irrigation requirement has decreased from 2,250-2,550 m^3/ha/time to 1,800-2,100 m^3/ha/time in the irrigation district. The effective rate of water use was increased from 0.35 in 1984 to 0.4-0.5 in 1986.

2. Uneven spatial distribution was improved because diversion of water in the upper reaches was carefully controlled so that there was sufficient water to convey to the lower reaches.
3. More efficient use of existing water resources led to an increase in the area irrigated. The increase in the average total volume of water diverted was only 89,000,000 m^3 while the area irrigated increased by 53,000 ha during 1984-86.
4. The previous system had led to a relatively egalitarian income distribution contributing to a low level of staff incentive and the need for an annual government subsidy. In recent years individual income related to individual work performance has initiated high economic payoffs.

Economic Contract Responsibility System and Development of a Diversified Economy

The economic contract responsibility system refers to the concept that water management should be more like business management. Management should assume the sole responsibility for profits and losses. For example, the Tuhai River Management Section of Yucheng County received only US$550 from the Water Conservancy Bureau since 1981. The example of the Tuhai River Management Section also demonstrates that the development of diversified enterprises as parts of water management helps to improve the economic efficiency of projects. It manages various enterprises such as a department store, a restaurant, and a pressing oil plant, and collects a water fee as well to pay operating costs. If its income exceeds the development/production funds quota, 40 percent of the extra income is given to the Water Conservancy Bureau, 40 percent is used for developing production funds, and 20 percent goes to the staff as rewards.

CONCLUSIONS

The North China Plain is subject to very uneven year-to-year precipitation. Rivers, diversion canals from the Yellow River, and a massive complex of underground aquifers are capable of providing water of greatly varying quality. This complicates the design of water projects. The history of the North China Plain reveals a gradual learning process about water-control design resulting in the development of comprehensive control works for combating drought, salinity, and waterlogging in the experimental district in Yucheng County. At the same time, economic reforms which encourage individual income being related to individual performance, management being responsible for the profits and losses of water-management enterprises, and which have encouraged economic diversification, have extended to the management of water resources. These reforms have increased the sense of responsibility of management units and their personnel so that water management and economic efficiency of projects have improved.