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IDENTIFICATION OF CAUSES OF POOR PERFORMANCE OF A TYPICAL LARGE-SIZED IRRIGATION SCHEME IN SOUTH CHINA

Mao Zhi

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SUMMARY

In the past, Zhanghe irrigation scheme was well-known for its poor performance. Since its rehabilitation in the last decade, however, it has been considered advanced. It is one of the large-sized irrigation schemes typical in South China, both in terms of its natural and social conditions and its experience of rehabilitation.

In this paper, an index system consisting of twelve techno-economical indices of evaluation of the irrigation and drainage schemes is presented. The performance of the scheme in engineering, economical and social terms can be quantified by these indices. The indices of Zhanghe scheme in the past and the causes of the unsatisfactory values of these indices are discussed. The effects of rehabilitation of this scheme are illustrated by contrasting the indices before and after the rehabilitation. The performance criteria and the main measures and experiences of rehabilitation in Zhanghe scheme are also introduced.

1. INTRODUCTION

Zhanghe Irrigation scheme (ZIS) has an irrigation area of 174 thousand ha and is the largest one in Hubei Province, China. It is situated in the central part of the province, north of the Changyiang (Yangtze) River.

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Its irrigation water is mainly supplied by a large-sized reservoir, the Zhanghe reservoir, which is built on a tributary of the Changyiang River-Zuzhang River. The reservoir is designed for the multipurpose uses of irrigation, flood control, water supply, power generation, etc, but in fact it is mainly used for irrigation.

In Zhanghe Irrigation District (ZID), about four fifths of the irrigation area lies in hilly regions, with only one fifth in the plains. The soils of the area are mostly clay and loam. The main crops are rice, wheat and cotton. The multiple cropping index is about two. Rice is planted over 86% of ZID and wheat is planted on 73% of the rice fields after harvest. The average evaporative capacity is 1353.1 mm, and rainfall is 937.7 mm, which is distributed in a highly irregular pattern both within and between years. Irrigation of rice is necessary in both dry and wet years, and the irrigation periods are from May to August.

ZIS was completed in 1965. Besides the water source projects, the canal systems include one main canal, five sub-main canals and 13,984 branch canals at 5 to 7 ranks. The total length of the above mentioned canals are 7,167.6 km.

The construction of ZIS fundamentally changed agricultural production in the area. The annual yield of rice increased from 3.0 t/ha after 1966 to 4.5 and 4.9 t/ha during 1975 and 1976. However, the rice yields remained at the same level, or even declined, during 1977 - 1980 due to poor performance and other causes, including policy, engineering and management aspects.

Since the 1980s, ZIS has been rehabilitated and it has now become one of the famous advanced irrigation schemes in China. Because ZIS is typical of large-sized irrigation schemes in South China both in natural and social conditions, a summary of its experience is of practical interest when investigating the status of policy, engineering and management before and after the rehabilitation. This paper, therefore, introduces and analyses indices of performance before and after rehabilitation and the main rehabilitation measures implemented.

2. INDEX SYSTEM FOR EVALUATION OF IRRIGATION SCHEMES

According to the eight national unified indices and in the light of the specific conditions of ZIS, the following index system is used. It consists of twelve techno-economical indices for analysing the performance of ZIS, organised into three groups. Most indices give the percentage of actual performance in terms of planned performance.

2.1 Group 1: Indices of irrigation water utilisation

The three indices used are

1. Efficiency of utilising irrigation water resource S (%)

$$S = \frac{Wp}{Wd} \times 100$$

where Wd and Wp are the design and actual possible annual quantity of irrigation water diverted from the water source in the same years (m^3/year);

2. Gross annual irrigation water quota M

$$M = \frac{W}{A}$$

where W is the actual gross annual quantity of irrigation water (m^3/year). A is the actual irrigation area (ha); and

3. Irrigation application efficiency E

$$E = \frac{Wf}{Wh}$$

where Wf is the total volume of water delivered to the points of use in field by the irrigation canal system (m^3); Wh is the total volume of water diverted from the headwork for irrigation (m^3).

2.2 Indices of irrigation area and engineering aspects of system

Again, three indices are used:

4. Efficiency of actual irrigated area F (%)

$$F = \frac{A}{Ad} \times 100$$

where A is the actual irrigated area and Ad is the design irrigated area (ha);

5. Percentage of area provided with field irrigation and drainage system D (%)

$$D = \frac{Af.a}{Af.d} \times 100$$

where Af.d and Af.a are the design and actual area provided with the field irrigation and drainage system (ha); and

6. Percentage of facilities in good condition G (%)

$$G = \frac{Ng}{N} \times 100$$

where N is total number of facilities for irrigation or drainage in a particular category; Ng is the number of the facilities in good condition (safe, integrated, functioning normally and attaining the design standard).

2.3 Indices of economic benefit

The six indices used are

7. Yield per unit area y (t/ha/year),

$$y = \frac{Y}{A}$$

where Y is the total annual yield (t/year) of crops in A (ha);

8. Yield per unit quantity of irrigation water y_w (kg/m³)

$$y_w = \frac{Y}{W}$$

where the unit of Y is kg/year and W volume of water supplied (m³)

9. Income from irrigation water charges per unit area (yuan[1] ha/year)

$$i = \frac{Iw}{Ad}$$

where Iw is the actual total annual income from irrigation water charges (yuan/year)

10. Irrigation benefit per unit area b (yuan/ha/year)

$$b = (y - y_0)c + (y^1 - y^1_0)c^1 - h$$

where y and y_0 are the annual yields of crops per unit area (t/ha/year) with and without irrigation respectively; y^1 and y^1_0 are the annual quantities of by-products per unit area with and without irrigation (t/ha/year); c and c^1 are the costs of agricultural product and by-product (yuan/t); h is the annual expenditure per unit area for irrigation (yuan/ha/year).

11. Irrigation benefit per unit quantity of irrigation water b_w (yuan/m³)

$$b_w = \frac{b}{M}$$

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[1] The Chinese unit of currency. In 1988 yuan = $0.268.

12. Percentage of financial self-sufficiency J (%)

$$J = \frac{I}{H} \times 100$$

where H is the total annual expenditures which includes salaries, administrative expenses and current expenditures (yuan/year); I is the total annual income from water charges and diverse other revenue sources (yuan/year).

3. THE OVERALL STATUS OF THE TWELVE TECHNO-ECONOMICAL INDICES ON ZIS BEFORE REHABILITATION AND ITS EVALUATION

10 to 15 years after putting ZIS into operation, ie during 1976 - 1980, the performance of the scheme began to decline. The poor performance was reflected in the twelve indices discussed above. In order to compare and evaluate the ranges and average values of the indices between 1976 and 1980, the values from ZIS are shown in Table 1, next to a notional normal level, derived from national and provincial figures.

The data table in Table 1 shows that the values of twelve indices on ZIS during 1977-80, especially E, D, G Yw, i and J, were all unsatisfactory.

The value of index E which mainly characterises the status of water waste is only about three quarters of the designed value. Such a value indicates that the waste of irrigation water was remarkable. The value of D reflects that the area which lacks a field drainage system was four fifths of the area in need of it. Value of G shows that about one fifth of the facilities were damaged. Value of y is only about two thirds of the normal level; that show both the low yield and the high water use. The value of i is only about one third of its normal level, thus the value of J is only about one third of the standard level. The values of y, i, b and J in Table 1 reflect that the economic situation is very poor. Therefore, it was necessary to rehabilitate to improve the performance of ZIS.

Table 1 The values of twelve indices on ZIS before rehabilitation

No	Names, symbols, and units of indices	Values of Indices			
		During 1976-1980 on ZIS		Design	Normal level or Standard Level
		Ranges	Average		
1	Efficiency of utilising irrigation water resource S (%)	75-93	88	100	95
2	Gross annual irrigation water quota M (m^3/ha/year)	6,400 -7,300	6,900	4,620 -5,700	5,000 -6,000
3	Irrigation application efficiency E	0.43 -0.53	0.48	0.65	0.60
4	Efficiency of actual irrigation area F (%)	55-98	91	100	100
5	Percentage of area provided with field irrigation & drainage system D (%)	10-30	20	100	100
6	Efficiency of facilities in good conditions G (%)	75-90	82	100	98
7	Yield per unit area y (t/ha/year	4.68 -5.76	5.16	6.00	6.00
8	Yield per unit quantity of irrigation water y_w (kg/m^3)	0.65 -0.82	0.75		1.15
9	Income from irrigation water charges per unit area i(yuan/ha/year)	7.2 -12.5	10.1		30
10	Irrigation benefit per unit area b (yuan/ha/year)	371 -477	420		600
11	Irrigation benefit per unit quantity of irrigation water b_w (yuan/m^3)	0.053 -0.065		0.061	0.85
12	Percentage of financial self-sufficiency J (%)	25-38	33		100

4. THE MAIN CAUSES OF UNSATISFACTORY STATE OF THE TECHNO-ECONOMIC INDICES

The causes of the unsatisfactory state of the techno-economic indices are many. The main causes were as follows:

4.1 Irrational regimes, organisations, policies and regulations for engineering and water management

4.1.1 Management organisations lack financial rights Although there was a professional management organisation, the ZIS Bureau of Management was set up by the government. There are five controlling stations under this Bureau, but they all lacked the right to make decisions by themselves on financial matters and on improvements to the project construction and management. Because the main income of the controlling stations was from the water charge, which was low, the main costs of projects were provided by the government. Investment plans and the organisation of the main projects were also decided by the government. Therefore, the projects often were not planned well.

4.1.2 Lack of a water code for water rights The ZIS Bureau of Management and its subordinate units did not have the right to allocate water. Local government, other administrative units and administrative officials usually interfered in the work of water allocation for their own partial and immediate benefit. Rational allocation and effective implementation are difficult in these circumstances.

4.1.3 Lack of policies and regulations for motivating staff to work hard. Besides the professional management organisations, there were many grass-roots management organisations of farmers. The staff of the professional organisations and the farmers who worked in the grass-roots organisations received a fixed salary which had almost no connection with the results of their work.

4.1.4 Irrational policy, form and rate of water charge In the past, as in many other regions in China, there was an irrational policy, form and rate of irrigation water charges in ZIS. The irrigation water charge rate was not based on the quantity of water used by farmers but on the irrigated area. The rate was very low, at about only 10 yuan/ha/year. For some years the farmers did not pay any irrigation water charges at all. As a direct consequence, there was a tendency to over-irrigation and wastage of water. This led not only to the loss of irrigation water but also to a decrease in rice yields. Therefore, in this area the value of index M is high, y and i are low. Moreover, the income of the irrigation management unit has decreased, which results in J being less than 100%; meaning the irrigation management unit was operating at a loss.

4.2 Imperfect irrigation and drainage schemes

4.2.1 Imperfect water-capture project and irrigation distribution schemes The water-capture project was imperfect. There were two spillways of the Zhanghe Reservoir in the design but only one of them had been completed. Thus, the normal water level in this reservoir had been lowered and the beneficial capacity had been decreased by 16% of the design value. The actual possible quantity of irrigation water and irrigation area and the corresponding indices (S and F) were all decreased.

The distribution systems, especially canal appurtenances, were imperfect. There were no bifurcation gates and control gates on the last distribution canals, and no water measuring devices on distribution canals. It was impossible to distribute the irrigation water in a planned manner and impose the water charge fairly.

4.2.2 Imperfect field irrigation and drainage systems In ZID, there are 71,000 ha of irrigation area of rice on the bottoms of hilly lands and plains. As a result of rice planting over a long time and diverting a large amount of water from water sources into the rice fields, the groundwater table in the rice fields has been raised year after year. Based on the local experimental data on the

plains, (especially on the bottoms of hilly lands), if the groundwater table cannot be controlled by the field drainage systems, the yields of rice will decrease by 10 - 15% and the yields of wheat after rice 20 - 25% due to the high level of groundwater table. Ten years ago, in the bottoms of hilly lands and plains, there were only 22,000 ha of irrigated area of rice provided with the field drainage systems. Lack of field drainage systems were one of the main causes of low yields of crops in the bottoms of hilly lands and plains.

In the past, most of the rice fields in hilly lands also had low yields because the field irrigation and drainage systems were not sound. Irrigation and drainage was carried out not by field canals, but with water flowing from 'plot-to-plot'; the loss of water and fertiliser was serious and the water temperature in the rice field was low. This caused the low values of indices of yields and economic benefits.

4.3 Poor maintenance of canal systems

As a result of poor maintenance for many years, the capacity of some distribution canals was reduced due to the heavy siltation, more weeds or termitaria. There were ten dangerous sections on the main and secondary canals due to erosion and scouring. The transmission line and communication line for the work of management were usually out of order.

4.4 The ponds were abandoned

Ponds are an important supplementary water source in ZID. Formerly the average long-term quantity of water which has been supplied by ponds was about 1,200 m^3/ha/year. After 1976, it was only about 600 m^3/ha/year because the farmers abandoned the ponds and transformed them into paddy fields. This practice further worsened the problem of water shortage in ZID and caused the decrease of irrigation area and yields of rice and the values of corresponding indices F and y.

4.5 Irrational water-management method and rice-irrigation method

As mentioned above, in the past it was impossible to apply advanced methods of management of water use because of the artificially imposed obstacles and the imperfection of canal systems. In fact, only a simple method was used in which the distribution of water to the secondary canals was based on the relative size of the irrigated area. It was a problematic method and usually led to over-irrigation in the early stage, water shortage in the later stage, over-irrigation in the upper zones and water shortage in the lower zones of the irrigation district.

Sometimes the rice fields could not be irrigated in time. The old rice irrigation method with a deep layer of ponded water of 80 - 150 mm on the surface of rice fields from the transplanting of rice shoots to the 'milky ripening' stage was widely applied by farmers. The data from the local experimental station, and the other places, had proved that by using this old method the rice yields were 12 - 20% less and the water requirement on rice fields were 20 - 35% higher than with a more advanced method which will be described later.

The irrational water-management method and rice-irrigation method were therefore also important causes of the unsatisfactory values of many indices.

5. THE PRINCIPAL MEASURES FOR REHABILITATION

The principal measures for rehabilitation of ZIS and improving its poor performance are as follows:

5.1 Reforming the administrative regimes

In 1979, an economic reform was started in China and the reform of regimes, policies and regulations of projects and water management also began to keep pace with it in every region. Under this situation, the following reforms have been enforced in ZIS after 1981.

5.1.1 Giving rights to the professional management units The ZIS Bureau of Management was given the responsibility (especially financially) for the rehabilitation and management of projects and water use. Interference by other administrative units and officials was prohibited. Therefore, the work on the rehabilitation and scientific management could be fully realised.

5.1.2 Economic contract and personal responsibility 'Systems of Economic Contract' and 'Systems of Personal Responsibility' have been implemented not only in the professional management units but also in the grass-roots management units organised by farmers. The income of each unit or person working for the rehabilitation and management is closely linked up with the results of their work.

5.1.3 Reforming the water charge The water charge rates were changed from the irrigation area only, to a dual system, one part based on the quantity of water used and the other on the irrigation area. Rates were raised to a realistic level. The rates for a quantity of water are 0.01 yuan/m^3 for irrigation and 0.03 yuan/m^3 for industrial use and the rate for the irrigated area is 12 yuan/ha/year.

After the water charge reforms, not only has the gross annual irrigation water quota (M) been decreased, but the yields per unit area (y), especially per unit quantity of irrigation water (y_w), have been increased. The income of the Bureau of Management of ZIS from the water charge (i) has also been raised to about six times that before reform. Thus, the financial ability of the Bureau for rehabilitation and scientific management was greatly strengthened.

5.2 Strengthening the construction and maintenance of the canal system and management of water use

As mentioned above, an imperfect canal system and poor management of water use are the main causes of irrigation water wastage and declining irrigated area and rice yields in ZID. In the process of rehabilitation, through clearing away the silt and weeds, treating the termitaria and reinforcing the dykes in the dangerous sections, the canals have

recovered their design capacity. 430 water measuring devices have been installed on distribution canals, and all the sections on the main and secondary canals with heavy seepage loss have been lined with concrete, clay or plastic film. In order to eliminate plot-to-plot irrigation and drainage, the irrigation and drainage field ditch systems have been constructed on almost the whole area of rice fields. All the above-mentioned measures have provided favourable conditions for planning the use of irrigation water and using the advanced rice-irrigation method.

Through rehabilitation, the principle measure in water use management was the implementation of the 'water use plans'. These were formulated for ZIS as annual and periodic plans. The annual plan outlines the amount of irrigation water and irrigated area for the entire year. The periodic plan formulates the quantity of irrigation water, irrigation area, water diversion and water allocation for each irrigation. Practice has demonstrated that the irrigation water can be delivered on schedule and then the quantity of irrigation water can be gradually decreased and the rice yield can be remarkably increased by implementing these two kinds of water use plans.

5.3 Using small reservoirs and ponds to increase water source

One of the main causes of decline of the irrigated area and rice yields in ZID is the shortage of water sources. Building small and middle-sized reservoirs and restoring ponds are important measures for expanding water sources. Through the process of rehabilitation, to date in ZID, 195 Type II (the total capacity is 100,000 to 1 million m^3) small reservoirs, 100 Type 1 (1 - 10 million m^3) small reservoirs, and 22 middle-sized (10-100 million m^3) reservoirs have been constructed. The total beneficial capacity of these reservoirs are 819 million m^3, equivalent to 87% of the beneficial capacity of Zhanghe Reservoir.

The characteristics of ponds are that they are widely distributed, provide timely irrigation, are easy to manage, and have a high water temperature. Irrigation with pond water aids rice growth. For a period after the construction of the Zhanghe Reservoir, people neglected the role of the ponds and many even filled in their ponds to make rice fields. Through this process of rehabilitation, at present, there are

85,969 ponds storing 249 million m^3 in ZID. Practice has demonstrated that ponds play an important role in the prevention of drought.

An irrigation system centred around the Zhanghe Reservoir and based on the ponds, and small and middle-sized reservoirs has gradually been formed. In this irrigation system, the water may be allocated to each other. At present, the average long-term total amount of stored water reaches over 1,200 million m^3. The problem of water shortage is nearing a solution.

5.4 Strengthening the work of research and experimentation

In 1968, an irrigation experimental station was established in the central part of ZID. In 1979, the work of experimentation and research at this station was strengthened and rice-irrigation methods have been included in the main research subjects. Based on the experimental results from 1979 to 1982, an advanced rice-irrigation method in the locality has been developed. In the past several years, this method has been gradually popularised on the greater part of the irrigated rice fields in ZID.

This advanced method uses the field irrigation and drainage systems to keep alternately a shallow ponded water layer, and damp and dry situations of soil on the rice fields at different growing stages of the rice. The water regimes on rice fields for this method are shown in Table 2. In all the growing stages, except the periods of drying the field in the sun and the yellow ripe stage, the water depth of the above-mentioned standards can be doubled after a rainfall, in order to make effective use of rainwater.

Based on the plot experiments at the station and the practices on the larger acreages, the yield of rice can be increased by 12 - 20%, and 20-35% of the irrigation water can be saved by using the aforesaid method in comparison to the old methods.

Table 2: General standards of water regimes on rice field in ZID

Growing stages	Depth of water layer on rice field (mm)
Transplanting of rice shoots	10 - 20
Revival of green	0 - 30
Early and middle stages of tillering	0 - 40
Late stage of tillering	Drain, dry the field in sun for 5 - 7 days
Booting to flowering	0 - 60
Milk ripening	0 - 40
Yellow ripe	Drain, dry the field.

6. THE EFFECTS OF REHABILITATION

The effects of rehabilitation on ZIS can be illustrated by the contrast between the twelve indices before and after the rehabilitation (Table 3).

The data in Table 3 shows that all indices have been improved through rehabilitation. Especially, the values of indices M, y and b show that the irrigation water has been saved by 15%, the rice yield and economic benefit has been increased by 48% and 40%. It is thus clear that, through rehabilitation, saving water has effected remarkable increases in crops yield and economic benefits.

Therefore, now, ZIS is one of the famous advanced large-sized irrigation schemes in China.

Table 3: The comparison of the values of twelve indices on ZIS between before and after rehabilitation

No	Names, symbols and units of indices	The average values of indices on ZIS		The values of the ratio of (A)/(B)
		Before rehab-ilitation 1976/80 (B)	After rehab-ilitation 1985/87 (A)	
1	Efficiency of utilising irrigation water resource S (%)	88	100	1.14
2	Gross annual irrigation water quota M (m^3/ha/year)	6,900	5,850	0.85
3	Irrigation application efficiency E	0.48	0.60	1.25
4.	Efficiency of actual irrigation area F (%)	91	100	1.10
5	Percentage of area provided with field irrigation & drainage system D (%)	20	95	4.75
6	Efficiency of facilities in good conditions G (%)	82	100	1.22
7	Yield per unit area y (t/ha/year)	5.16	7.65	1.48
8	Yield per unit quantity irrigation water y (kg/m^3)	0.75	1.31	1.75
9	Income from irrigation water charge per unit area i (yuan/ha/year)	10.1	55.6	5.50
10	Irrigation benefit per unit area b (yuan/ha/year)	420	588	1.40
11	Irrigation benefit per unit quantity irrigation water b (yuan/m^3)	0.061	0.101	1.66
12	Percentage of financial self-sufficiency J (%)	33	105	3.18

7. CONCLUSIONS

Many old irrigation and drainage schemes in China need to be rehabilitated due to their poor performance. This performance can be identified by an index system which consists of three kinds of techno-economical indices: 1) Indices of utilising irrigation water, 2) Indices of irrigation area and engineering aspects of the system, and 3) Indices of economic benefit.

The main causes of poor performance on irrigation and drainage schemes are from not only technical but also social aspects. The principal measures for rehabilitation may be to resolve both the technical and social problems.

The effects of rehabilitation can be illustrated by the contrast between the values of the techno-economic indices before and after rehabilitation. Based on the analysis of the data of these indices from a typical irrigation scheme in South China, the irrigation water can be saved by 15%, and the rice yield and economic benefit can be increased by 48% and 40% respectively through rehabilitation. It is thus clear that the effects of rehabilitation of irrigation and drainage schemes are remarkable.

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