Water management strategy and irrigated area modernization: The Tunisian case

Lebdi Fethi[1]

1. Administrative organization

The Ministry of Agriculture and Hydraulic Resources is in charge of water resources (mobilization and usage) and agricultural production as well as drinkable water (SONEDE is the state company responsible for potable urban water and DC/GR is responsible for potable rural water). The Ministry of the Environment, among other responsibilities, is in charge of studies on environmental impact analysis, environmental systems' surveillance and urban hygiene (ONAS: The National Office of Cleansing).

In Tunisia, integrated water management is underway and is governed by:

- General, central, technical administration.
- Regional secretariats for agricultural development.
- Regional agencies belonging to SONEDE.
- Regional agencies for hygiene (ONAS).
- Secadenor (a company responsible for water transfer).
- The Institute for Research and Higher Agricultural Education; this establishes priorities for applied research after consulting Technical Directions in order to fix financial support.

2. Water resource plans

- Plans to guide individual basin management. There is need for a transfer network between basins that sometimes have excess supply, especially when rainfall is heavy (protection against flooding as well as storage in other basins with deficits is needed).
- Plans and priorities for projects to satisfy potable water needs for each basin.
- Conjunctive management of surface and underground water for the central part of the country where rainfall is low and variable.
- Plans for water in the south, especially for managing underground water tables and the creation or the rehabilitation of oases as well as plans for water harvesting.
- Plans to supply potable water at rural and urban scales.
- Integrating with stakeholders to develop operational plans for the management of floods and drought that are backed by participatory management and water users' associations.

Table 1. Evolution of mobilized resources

Nature des ressources	Ressources potentielles (1)	Ressources exploitables (2)	Ressources mobilisées (3)		
			1991	2000	Prév. 2010
Eaux de surface	2 700	2 100	1 250	1 480	2 010
Eaux souterraines	1 970	1 970	1 500	1 750	1 870
– Nappes phréatiques	720	720	700	750	720
– Nappes profondes	1 250	1 250	800	1 000	1 150
TOTAL	4 670	4 070	2 750	3 230	3 880
Taux de mobilization (3/2)	–	–	68%	79%	95%
Eaux usées traitées	250	200	85	148	210

Source: Water 21. Agricultural Ministry (2000).

[1] Ministry of Agriculture and Hydraulic Resources, Tunisia.

3. General context of water management

- Scarcity of water resources and salinity:

  460 m^3/per capita in 2000 to increase to 345 m^3/per capita in 2025;
  65 percent of water resources have salinity exceeding 1 g/litre
- Water mobilization and management: The mobilization rate was 80 percent in 2000, to increase to 95 percent in 2010.

Table 2. Water demand increases via sectors

SECTEUR D'USAGE	1990 Mm^3	2000 Mm^3	2010	
			Mm^3	%
EAU POTABLE	260	365	502	16
EAU INDUSTRIELLE	85	110	123	4
IRRIGATION	1 575	2 165	2 540	80
DEMANDE TOTALE	**1 920**	**2 640**	**3 165**	**100**

The future increase in demand is related to:

- Reduced potable water availability, particularly in rural areas.
- The extension of irrigated areas to improve food security in a country prone to frequent droughts.
- Supplying the expanding industrial and tourism sectors (tourism especially requires good water quality).

Addressing water use rationally in most sectors, particularly irrigation, is needed to:

- Avoid water wastage.
- Adjust water tariffs and reduce prices.
- Enhance the economic value of existing water resources.
- Centralize water management administratively.

4. General framework of the water management policy reforms

- The re-examination of policies and instituting certain reforms started in the early 1990s as part of a major structural adjustment programme. This programme focused on measures to stimulate swifter economic progress; at the same time it awarded a more important role to the private sector and strove to preserve natural resources.
- Heightening awareness on water scarcity in order to assure long-term national development.
- Picking a specific strategy for the water sector to ensure:
  - achievement of the programme for mobilization of conventional water resources;
  - development of the use of non-conventional water resources (desalinated, recycled and saline);
  - integrated management, conservation and protection of water from pollution;
  - setting up instruments to manage demand in various sectors in order to reach water economy of 30 percent in every sector by 2030.

Tunisian water policy has always been accompanied by complementary economic and institutional measures:

- State grants and encouragement of agricultural investment.
- Sectoral organization and legal as well as institutional instruments.
- Promotion of rural areas.

Efforts are made to ensure contributions from water users, particularly for potable rural water and irrigated agriculture, which has local economic value or to encourage agricultural production that is not vulnerable to foreign competition (citrus crops, dates, olive oil, fruits or market gardening).

Irrigated agriculture is promoted to enhance its role in regularizing the market and to complement rain-fed agriculture which is very important (in the Maghrebin context, especially for cereals and fodder crops that are necessary for livestock production and milk in particular).

5. Potable water management and hygiene policy

Although relative demand for potable water has declined, the need for quality and hygiene called for SONEDE to create an economic water strategy based on technical and socio-economic aspects.

Technical aspects

- Intensification of campaigns for leak detection in water networks.
- The rehabilitation of pipelines by using stronger material.
- Introduction of standard individual flow meters and the replacement of old units.

System regulations are being revised and advanced metering and management techniques that make use of the latest technology are being adopted.

These measures improve network efficiency (96 percent for water supply and 86 percent for distribution). Globally, potable water network efficiency was approximately 74 percent in 1994 and 83 percent in 2005.

Socio-economic aspects

SONEDE created a progressive tariff system in the form of adjustment to usage. There have been average annual increases of about 3 percent during the last 15 years. The main advantages of this tariff system are:

- Financial equilibrium in water system management thanks to tariff equity at the national scale.
- Reduced tariffs so socially underprivileged groups have access to potable water.
- A reduction in demand by heavy consumers owing to stiff tariffs on their consumption.

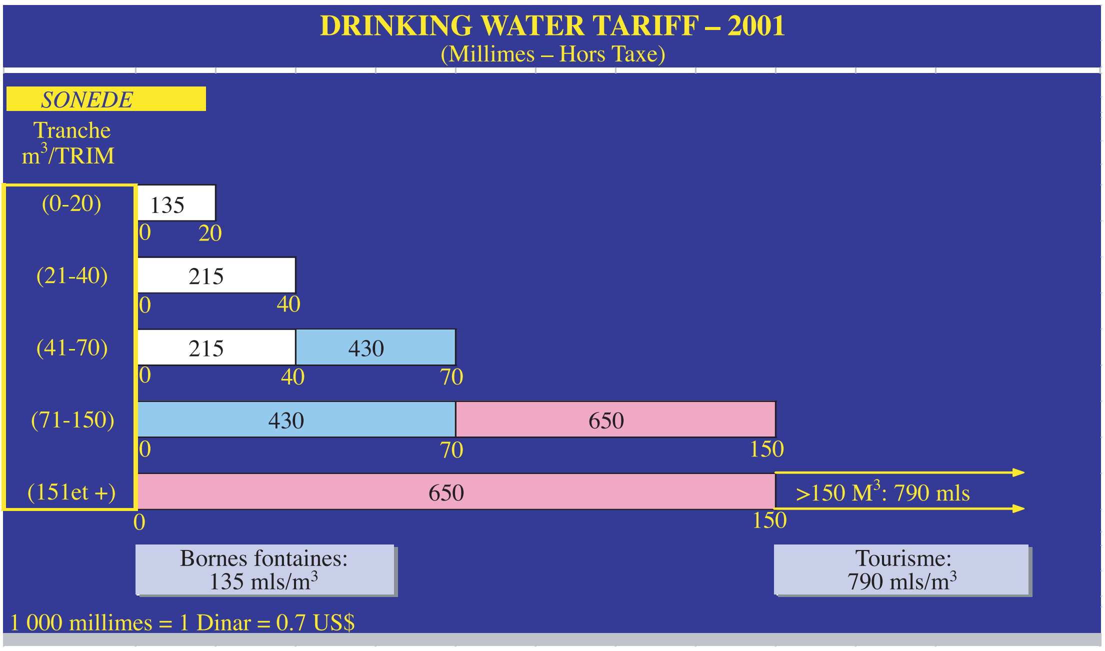

Figure 1. Potable water tariffs in 2001

The water strategy was re-inforced in 2001 through different measures that aimed to address consumption:

- Intensification of programmes on public information and sensitization.
- Periodic analysis of major consumers.
- Introducing mandatory standards for equipment used in water distribution to the public.
- Awarding specific financial incentives for investments in the production and commercialization of non-conventional water resources, as well as auditing of the water economy.
- Encouraging the private sector to participate in the production and distribution of non-conventional water for industrial and tourist projects.

The service rate in the rural environment peaked at 90 percent at the beginning of 2006 and has subsequently been ameliorated.

The hygiene policy generated considerable growth and provided 85 percent of the population with hygienic water supply. It was particularly marked by the coordination and management of the sector by the National Office of Cleansing (ONAS), the indexation of fees to volumes of potable water consumption and the development of the use of recycled water for agriculture.

6. The policy for agricultural water management

The irrigated sector reaches only 7 percent of the useful agricultural area in the country but it contributes in a significant way to agricultural development. It contributes 35 percent to the value of agricultural production and 20 percent to agricultural exports; it employs 20 percent of the labour force. However agriculture is a heavy consumer of available water resources. For example: 1 000 ha of irrigated area consumes the same water volume as a city of one million inhabitants with 100 litres/person.

To improve the performances of this sector, a national strategy for water economy in irrigation has been adopted. This strategy addresses the rehabilitation and modernization of irrigation systems and techniques, prioritizing irrigation demand and more autonomous management between sectors.

6.1 The decentralization of water management and the promotion of WUAs and participatory management

Currently, 970 water users' associations (WUAs) run 70 percent of the irrigated area and this will increase in future. In this context there is a need to promote participation by local women through:

- Technical training.
- Emphasizing the participatory approach in the development of agricultural programmes.
- The production of audiovisual and printed material that cover women's activities in agriculture and product processing.
- Involving associations interested in the promotion of rural women in agricultural management.

6.2 Pricing irrigation water

Since 1990, a regular increase in water tariffs has been adopted which has allowed recovery of almost all costs for use and maintenance of irrigation systems. The collection of future costs will be considered in a later phase. Preferential tariffing is awarded to practices with strategic characteristics (cereals, fodder crops) and the use of recycled water for irrigation.

6.3 The water parcel programme

This programme has made considerable progress since 1995 and has been favoured with grants for irrigation equipment (40, 50, 60 percent for large, medium and small projects). Currently 75 percent of the irrigated surface is now equipped; this will reach 95 percent in 2009.

A preliminary evaluation of this programme seems encouraging. Average irrigation efficiency has increased thanks to newly introduced techniques. Agricultural yields have improved by 70 percent and there have been additional benefits.

6.4 Action for training and research

- Management of surface and underground water: Conjunctive management.
- Water and soil conservation.
- Rural drinking water.
- Participatory management of water demand.
- Integrated management of water resources in a basin at the aquifer level.
- A national information system on water resources.
- Use of recycled water.
- Rural hygiene.
- An information system and a national surveillance network on water pollution.

7. Lessons learned from the Tunisian experience

There is a need to integrate different components of a strategy for demand management, which has technical, economic and institutional aspects. The isolated reforms of the past accomplished few significant goals. The progressive establishment of different reforms is recommended for adoption in the local context to ensure greater involvement of the different parties concerned, particularly users and their organizations.

There is a need to balance water export-import (physical and economic balance). The water quota per capita in Tunisia in 2004 was 417 m^3/year, which is much less than the global water threshold of 950 m^3/capita/year. The objective is to re-organize agricultural production to the volume of used water, either exported or imported, in the context of irrigated cultivation with enhanced additional value. Table 3 provides a chronology of water usage between 1995 and 2003.

Figure 2 allows assessment of imported and exported amounts over the given period. Average annual consumption per capita is mainly derived from local sources but also from imports. Quantities of imported water are much higher than those exported. In economic terms however the cost of 1 m^3 of water exported is significantly higher than its imported counterpart according to physical availability. Thus an imbalance remains between physical and economic usage.

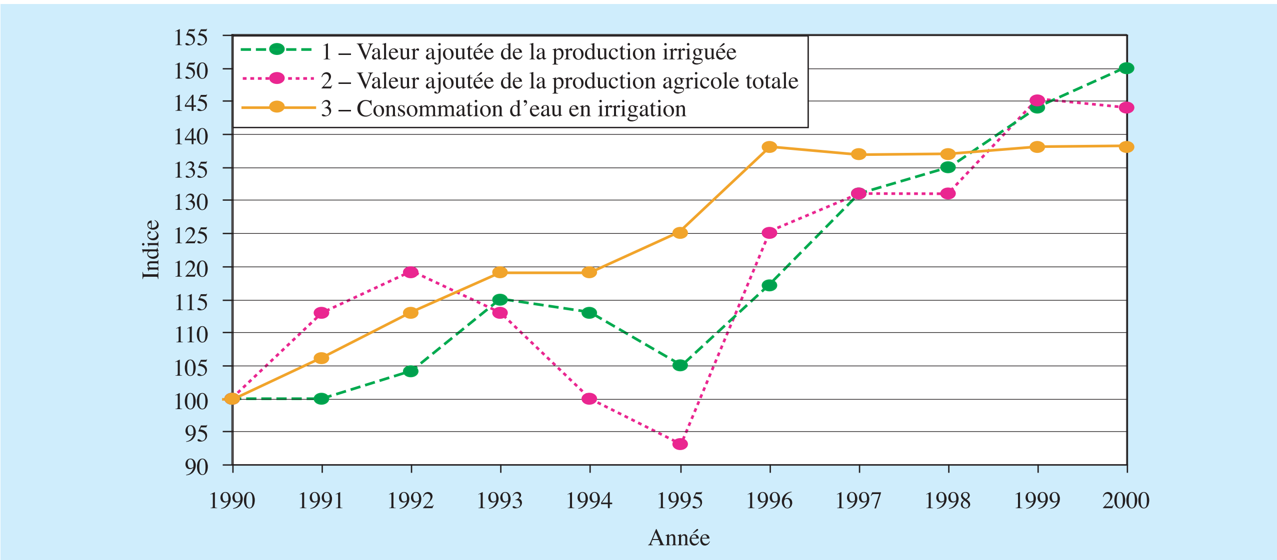

Figure 2. Evolution of water consumption and of the added value of the irrigation sector

Table 3. Statistical chronology of water imports/exports, 1995–2003

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003
TOTAL exported (Million m^3)	0.24	0.13	0.27	0.29	0.29	0.47	0.47	0.48	0.30
TOTAL Imported (Million m^3)	5.50	2.50	4.00	3.90	4.10	5.00	5.80	5.20	3.90
Positive balance (Million m^3)	5.26	2.39	3.75	3.70	3.82	4.62	*5.39*	4.70	3.67

Ideas on irrigation modernization

Sun Xihuan[1]

1. Irrigation modernization — definition

In 1997, FAO reported that there was general recognition that “irrigation modernization is a process of progressing in the technology and management of irrigation systems, combined with institutional arrangements and regulations, and its general objective is toward utilization of labour force resources, water resources, economic resources and environment resources, as well as providing services to farmers and their water distribution terms”. Generally, irrigation modernization is the process of irrigation progressing with time, which implies that existing systems reform, new technologies are adopted, administrative principles are improved and good water supply services are provided through efficient utilization of labour, water, economic and environmental resources.

2. Water conservation and irrigation modernization

Water resources are not abundant in China. Average annual water availability per capita is 2 200 m^3, ranking China 121st in the world. With rising population and a developing economy, demands for water are increasing, making the gap between water supply and water use much wider. Narrowing the gap, providing dependable water resources and increasing water use efficiency are important for the sustainable development of the national economy. Saving water and protecting water from pollution are included in China’s current water law.

In China, agriculture water use constitutes 70 percent of total national economic water use. Irrigation, as the main agricultural water user, has low water use efficiency. Therefore, water-saving practices in irrigation areas are an important objective for irrigation modernization.

Professor Maozhi, the Chinese engineering academic, suggested that objectives for modernizing irrigation and water conservancy techniques should follow the aforementioned FAO definition of irrigation modernization in the context of the lack of environmental awareness in China. Seven basic attributes have been proposed in this regard:

1. Protective measures should be in place to address flooding and waterlogging and to prevent loss of life and property that may result from the irrigation project.
2. Irrigation and drainage should be fine-tuned and reliable; adopt broad water-saving technology and understand the economic and environmental benefits of water resources.
3. Avoid pollution and protect and enhance the ecosystem, as well as the water quality of headwaters, drainage areas, surface and underground water in irrigation districts.
4. Guarantee drinking water safety and electricity supply so inhabitants of the irrigation district have a comfortable life and living environment.
5. Employ modern information management systems and optimize water distribution systems; ensure that advanced technology is used in engineering projects, maintenance and repair activities, and for management tools.
6. Deliver efficient management, analyse procedure scientifically and establish an equitable water price system.
7. Establish irrigation and drainage technical services and an extension system.

3. Irrigation modernization in Shanxi

When analysing agricultural irrigation and water resources in Shanxi Province, it is plain that modernization of irrigation and water conservancy techniques can not only improve the irrigation service but also resolve

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water shortages and enhance irrigation efficiency. The main components of irrigation modernization can be disaggregated as follows:

3.1 Water saving by engineering design

According to the latest research, the annual average water resource supply of Shanxi Province is 123.8 BCM. The annual average water resource per capita is 381 m^3. Water availability per square kilometre of cultivated land is 2 700 m^3. Shanxi Province is deficient in water supply. Water saving is therefore of the utmost importance for our future, to guarantee socio-economic development, alleviate conflict between industry and agriculture and promote the sustainable development of population, resources and the environment. No matter the location, new construction or reconstruction, water saving should be carried out via proper engineering design.

3.2 Integration of water conservancy measures

There are many types of water-saving measures that use engineering solutions (e.g. methods for preventing leakage during water transportation and distribution, irrigation methods and irrigation equipment), agricultural measures (e.g. film mulching, stubble retention management), biological measures (cropping pattern modification, seed improvement, drought-resistant varieties) and policy measures (awareness campaigns, water price regulation). The integration of different water-saving measures can enhance water-saving activities.

3.3 Infrastructure

Most of the hydraulic engineering structures in Shanxi Province were constructed between 1950 and 1960. Due to decreasing investment, current projects in almost every irrigation district have inadequate infrastructure, which affects water transportation and distribution, resulting in water losses. Because most of the main and branch canals are earth channels, seepage control is only 49.9 percent and seepage prevention is 41.8 percent. According to the Second Water Resources Evaluation of Shanxi Province, the average canal coefficiency of the province was 0.66, field application coefficiency was 0.7 and irrigation water application coefficiency was 0.46. Therefore, it is important to introduce infrastructure to enhance irrigation efficiency, improve the water supply service and realize irrigation modernization.

3.4 Rational utilization of water resources

In Shanxi Province, annual surface water utilization approximates 2.5 billion m^3 and groundwater utilization is 4 billion m^3. Overexploited groundwater has reached 0.7 billion m^3. Agricultural water usage is 4.2 billion m^3, about 64.6 percent of total water usage, of which groundwater utilization is about 1.75 billion m^3. Overexploited areas are found in Datong, Xinzhou, Taiyuan, Linfen and Yuncheng, where there are many environmental problems. Therefore, water carrying capacity must been taken into account in the course of water resource exploitation for sustainable usage.

3.5 Diversification of the investment system

Irrigation infrastructure construction involves many tasks and requires considerable funding. Market economy regulation and diversification of investment systems should be carried out to accelerate infrastructure construction. Irrigation should aim at providing services to farmers and agriculture. Therefore, during irrigation modernization, increased government responsibility, expanded government investment and structural integration are needed to diversify investment systems that should be dominated by government investment inputs. Proper laws are required on water price formulation and water tariff collection; improved education and management techniques are essential.

3.6 Mechanization of construction projects

In recent years, mechanization and semi-mechanization of construction projects, such as earthwork excavation and concrete linings for canals, have enhanced work efficiency and the development of irrigation district construction.

3.7 Establish water users' associations

The development of irrigation districts needs farmers' support and water users' associations (WUAs) should be created. Agriculture water conservancy is closely connected to farmers' livelihoods. We should insist on farmers' participation and democratic decision-making in WUA establishment according to the "Suggestion regarding enhancing the establishment of farmer water users association" issued by the Ministry of Water Resources, the State Development, Reform and Planning Committee and the Ministry of Civil Affairs.

3.8 Security of the system

The security of the system is an important component of irrigation modernization. System modernization can assure ecological security through water quality monitoring, facility maintenance and information dissemination. The irrigation district should be assigned with special safety supervisors, safety regulations, as well as warning mechanisms and emergency response modes.

3.9 Automation of system monitoring

Automation of system monitoring is an important feature of irrigation scheme management. Manual collection of data is now mostly obsolete. It is essential to adopt new technology to realize automatic data retrieval and establish a suitable information system. Automated technology can not only target plant water demand, waterheads, water quality, precipitation, evaporation, soil moisture and soil fertility, as well as flow in channels and pipes, water table levels and siltation factors, but also monitor and remotely control the operation of gates and pumping stations.

3.10 Information dissemination

Information dissemination on irrigation management is an important component to realize management of information sharing and irrigation modernization. Currently, irrigation district management and sector management mainly use traditional methods and have not accomplished effective administration and maintenance of various data or enhanced information sharing. This not only seriously affects irrigation district management but also prevents water administration departments at different levels from identifying cutting edge trends in irrigation management. Therefore, the main mission of irrigation district management is to elevate information dissemination to a higher standard.

3.11 Irrigation water supply service

The general objective of irrigation modernization is to serve farmers with regular water supply through different modern technologies. Therefore, not only good water supply infrastructure, but also fine-tuned water computation facilities are needed. Irrigation districts should have an hydraulic information feedback strategy and scheduling strategy to realize rapid water supply. Success also depends on training farmers in good irrigation and drainage practices.

3.12 Scientific evaluation system

Irrigation modernization depends on establishing modern evaluation systems that are fast and efficient. They should include scientific evaluation indices and evaluation methods to assess current situations and the potential for development in irrigation districts and further provide specific suggestions.

4. Conclusion

Irrigation modernization is a long-term effort comprising many technological and economic factors. For such modernization in China, farmers are the principal actors, the government is the overseer, the market is the foundation, technology is the facilitator, service is the root and efficiency is the objective.

SUBTHEME II:
OPTIONS FOR TECHNICAL AND MANAGERIAL IMPROVEMENTS AT THE SYSTEM AND FARM LEVEL

The impacts of water-pricing reform on agricultural irrigation in China

Li Yangbin[1]

1. Agricultural irrigation: Status and constraints

Agricultural irrigation plays an important role in ensuring national food security. Since the establishment of New China, the Chinese Government has attached considerable importance to the development of agricultural irrigation. More than 5 600 large- and medium-scale irrigation districts and 400 000 small-scale irrigation districts have been created, increasing the irrigated area from 16 million ha in 1949 to 56 million ha currently. These irrigation areas have become the foundation for grain, cotton and oilseed cultivation; annual food production from irrigation areas accounts for 70 percent of the national total and 90 percent of economic crop, fruit and vegetable outputs. About 360 billion m^3 of water are used for irrigation (69 percent of total national water use). Nearly 500 000 people are employed by irrigation management departments. Agricultural irrigation has made tremendous achievements but is confronted by many new problems and challenges.

1.1 The low price of irrigation water and serious deviation of price from the value

Irrigation water prices are controlled by the government. During the planned economy period, agricultural irrigation projects were subsidized by the government and farmers contributed their labour, so there were no or minimal water fees. Since reform and liberalization, the water price of irrigation comprised partial cost and farmers' compulsory labour as well as farmers' voluntary labour as investment (the "two labours"). Irrigation canals were maintained by the "two labours". However management departments could barely operate the system. With the reform of rural taxes and fees, the "two labours" were abrogated and new problems related to agricultural water fees emerged. On the one hand the water price was still governed by the government (50 to 60 percent of the cost without the compensation of the "two labours"), on the other hand the government strongly supported the "three rural issues" (Agriculture, Rural Areas and Farmers) with elimination of agricultural fees and subsidized prices for grains, with apparently no reason to charge water fees for irrigation use. Furthermore, grain prices are stable currently which provides some room to increase the price of agricultural water.

1.2 Excessive agricultural water fees and major decline in water revenue

In the past, water fees were collected by villages and townships by unit area and then handed over to water management departments. After the reform of the township institution, the number of rural water management groups declined significantly. The original water fee system has been plagued with problems, and a new system has not been established yet. Irrigation water revenue has dropped sharply. According to a special survey carried out recently by the Department of Finance and Economics, Ministry of Water Resources, the agricultural water charge rate has dropped by 15 to 30 percent in most provinces and over 40 percent in some provinces. As irrigation districts and their employees depend completely on water fees, this had resulted in the deterioration of maintenance and management. The water management departments are finding it difficult to survive and develop.

1.3 Serious waste of water resources

Due to the low water price and poorly equipped irrigation projects, especially the dearth of field projects, more than 95 percent of China's agricultural irrigation adopts surface irrigation and most irrigation schemes

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rely on flood irrigation. Currently, the agricultural water use coefficient is only 0.45, and there is a serious waste of water resources.

1.4 Serious ageing and disrepair of irrigation and drainage facilities

Due to the lack of specific investment in field work for many years, facilities are now ageing and falling into serious disrepair. Now the abolition of the “two labours” and the policy of “one issue one discussion” have resulted in a significant reduction of investment in irrigation projects. In the past, about ten billion person-days were invested in winter repair of irrigation facilities or approximately 100 billion yuan (10 yuan/person-day). But departmental investment has not made up for shortfalls. Water management departments and farmers have not maintained or repaired field facilities. Therefore, the ageing and disrepair of irrigation and drainage projects have worsened.

2. Impacts of water price reforms on agricultural irrigation

Based on the aforementioned problems, it is clear that water fees provide the main support for regular operation of irrigation and drainage works, and water price reforms have had significant impacts on national food security, the development of water-saving irrigation, the creation of a water-saving society and accrued benefits.

2.1 Water price reform affects national food security

Grain production is a high-risk industry and the total grain output of the state has experienced major fluctuations. Grain production reached 512.3 billion kg in 1998 but dropped to 430.65 billion kg in 2003, declining by 16 percent. To address this serious situation, the government adopted a series of effective measures that improved grain output to 469.45 billion kg in 2004. This indicates that China’s agricultural infrastructure is still fragile. More than half of the country’s land occupies arid or semi-arid areas and rainfall cannot meet crop needs so crops must be irrigated. In the south of China, due to rainfall anomalies that impact on stable agricultural production, irrigation and drainage facilities are also needed. Irrigation in China plays an important role in agricultural production. If water prices are unreasonable and farmers fail to make profits, they will marginalize grain crop cultivation. Subsequently the grain security strategy is jeopardized and crop diversification will disappear.

2.2 Water price reform impacts on water-saving irrigation and the water-saving society

Agricultural irrigation is a major water user. If the price is too low, the farmers will not be compensated for their water-saving activities and they will not cherish water resources; thus flood irrigation will resume and further serious water wastage will result. So the farmer is the mainstay of water-saving irrigation and economic interest is the only real impetus. If the water price is raised to a certain level and the farmers receive water-saving compensation, they will restrict their water use. Shultz, the Nobel-winning economist, indicated that the world’s farmers calculate costs, benefits and risks. In closed, isolated and scattered areas, they are prudent “economists”. The fundamental way to solve the problem of water shortages in China is to build a water-saving society. No matter how strong the demand is for state water conservancy, if the water price mechanism is unreasonable, not only farmers but also water management departments will use more water to maximize revenue for their own interest.

2.3 Water price reform will affect farmers’ economic interests and rights

If the pricing mechanism is inequitable, farmers’ profits and income will drop. Although non-farming income accounted for more than 50 percent of farmers’ average income in recent years, agricultural production is still the main source of income for farmers in the central and western regions. Imbalanced development in China between urban and rural areas is worsening and the income gap between urban and rural residents has grown, from an absolute gap of 209 yuan in 1978 to 7 283 yuan in 2005 and a relative gap from 2.57: 1 to 3.22: 1. If the water price rises, farmers’ profits will decline. Farmers’ benefits will not be ensured without water-saving compensation.

2.4 Water price reform affects the wages and welfare of employees and the stability of the staff

Water fees are the main income of water management departments. If the water fee drops sharply, it will be very difficult for water management departments to survive and develop. Most water management departments are self-supporting institutions and water fees are the only source of revenue to pay for employees' wages and maintenance of water infrastructure. With lower water charges, many water management departments find it difficult to guarantee wages for employees; this generates staff instability, poor management and increasing appeals to higher authorities for support. The aforementioned survey revealed that about 70 to 80 percent of revenue from water charges is used for personal costs and 20 to 30 percent for project maintenance.

3. Countermeasures and suggestion

Agricultural water price reform is a very complex task. It must be adjusted and promoted continuously. According to the National Development and Reform Commission in 2001 "on the issue of the price of water for agricultural reform", in principle, agricultural water price was to be regulated to its supply cost step by step over a three-year period. Now that five years have elapsed, the price has not reached its cost, but dropped sharply. There is evidence that water-pricing policies did not fully conform with reality. When an attempt was made to establish a pricing mechanism to promote water conservancy it resulted in variegated economic interests among the stakeholders (the government, management departments and farmers). As farmers are vulnerable and agriculture is a weak industry agricultural water price reform cannot be fully market-oriented. In the past, the agricultural water-pricing mechanism relied on part of the water cost and the farmers' "two labours" to maintain irrigation operation. Now it is necessary to study the price compensation mechanism including the government pricing system and compensation methods. Water price reform also includes water fee collection. In fact, there are many problems related to water fees. Traditionally and especially in the south of China, water was generally charged by area; the north partly introduced water measurement but mostly charged by area. In the past, water fees were collected by villages and townships. Now, water fees are charged by management departments, WUAs and townships. Zhai Haohui (Vice-Minister of the Ministry of Water Resources) stressed that water price reform should persist to alleviate farmers' water burdens, develop water-saving activities, promote the development of agricultural production and enforce water conservancy, especially benign irrigation. The ultimate aim is to create an equitable water price mechanism and to establish an equitable water measurement and charge system. Concerning water price reform, the following three measures are proposed:

- Compensate farmers who are within the water use quota and do not compensate or charge extra for overuse. According to the aforementioned survey, water cost is about 840 yuan/ha, while the actual water fee is only 300–420 yuan/ha so the actual water price is only half of its cost. There is sufficient room to raise the water price, because grain prices have been basically stable in recent years, farmers' income has risen slowly and the state is drawing up policies to increase farmers' income. As the "two labours" have been abolished to reduce the burden on farmers, this should be some compensation for the cost of water.
- Grassroot reform of the water management mechanism. Reform of irrigation districts includes two components: (1) Reduce management staff and appoint specific maintenance staff. Maintenance of the irrigation district should be separated from management. (2) Transfer the management of secondary canals to WUAs. Formerly this was done by the government at town and village levels. Water fees were collected by the government at both levels. Appropriation, interception and random charging often occurred. With the establishment of WUAs, the irrigation facility will be managed by the WUA which will also collect water fees. Practice shows that irrigation water use per hectare declines — as do water charges — in irrigation areas managed by WUAs because they collect the fees and hand them to water supply institutions directly.
- Build a water rights mechanism. Irrigation water rights are centuries old. In past decades, during industrialization and urbanization, many agriculture water rights and water conservation facilities were transferred to industries and farmers received no financial compensation, which was unfair. Now that

industries and cities have progressed they should compensate agriculture and support rural development. Approximately 100 billion m^3 of agricultural water has been transferred to industries and cities. If 0.1 yuan/m^3 domestic and industrial water use is levied in compensation, then about ten billion yuan *per annum* will be raised. Currently, pilot demonstration projects for water rights transfer in Inner Mongolia and Ningxia have achieved good results. However, annual water resources vary with climatic conditions. In drought years, supplies decrease accordingly. In the past, water supply for industries and cities received first priority and agriculture second priority. The farmers sacrificed much for national benefit. Therefore a water rights mechanism for compensating farmers must be built. Worldwide, governments and enterprises generally compensate farmers for no cultivation in drought years. In China, more than 6.67 million ha of arable land are affected by drought each year. If farmers received 1 500 yuan/ha, this would amount to ten billion yuan/year.

Technical options at the system level: Canal lining and canal operation control

Herve Plusquellec[1]

1. Introduction

In the last 30 years, hundreds of millions of dollars have been invested by developing countries, with or without the assistance of donor agencies, in rehabilitating, upgrading or modernizing existing irrigation systems. There are no reliable statistics on how much of these investments were allocated to rehabilitation, in many instances a euphemism for deferred maintenance and for modernization. Analysis of past investments is further complicated because rehabilitation/modernization is frequently associated with the completion of irrigation schemes such as tertiary systems, on-farm development schemes or drainage works deferred during initial construction. Donors and governments have often misused the terms “rehabilitation and modernization” and it should be realized that they have very different meanings. The author’s opinion is that the bulk of investments during the last three decades addressed rehabilitation activities and not modernization for a number of reasons, most importantly, operators’ ignorance of the inherent deficiencies in existing systems, insufficient knowledge of new technologies and overall lack of training.

The ultimate objectives of irrigation modernization are to increase the income of the rural population and to meet the food requirements of the increasing population. These broad objectives are achieved by improving the performance of irrigated agriculture and the use of declining water resources for the agriculture sector because of increasing competition with other economic sectors, including the environment. In practical terms, the aforesaid objectives are translated into water saving in conveyance and irrigation distribution systems and at the farm level as well as improving the quality of water delivery service to the users. Modernization should also result in a reduction of the operation and maintenance costs of an irrigation system — borne or not borne by the users.

For some time now it has been recognized that the performance of large irrigation systems falls far below expectations. However the modernization of large-scale irrigation systems has not attracted the attention of donor agencies, possibly because agricultural production has kept pace with the increasing demand for food production worldwide. The intensive use of groundwater during the last few decades has certainly contributed to meeting food requirements in many countries. More reliable water delivery and declining extraction costs due to advances in technology and in many instances government subsidies for power and pump installation have encouraged private investment in groundwater extraction. For example, in India the area irrigated by groundwater rose from about 25 percent in the 1960s to well over 50 percent in the 1990s. Overall, China has over 27 percent of its area irrigated from groundwater and about 50 percent in the North China Plains. The percentage can reach as much as 80 percent in developed countries with a mild climate (Germany) and in arid countries (Saudi Arabia, Libya).

In many countries, groundwater use has reached its threshold. Groundwater is mined in large regions of India and Pakistan, in the northwest region of Mexico, in Egypt and Yemen and in the North China Plains. Groundwater depletion results in higher pumping costs and declining water quality. Complacency in neglecting or postponing the modernization of large surface water irrigation systems is no longer acceptable.

2. Technical options

The term “modernization” is defined as the adoption of new technical or managerial tools that result in a substantial improvement in performance. Modernization could be applied to design, construction techniques and materials, operation and maintenance. This paper will focus on the technical options for improving the efficiency of water conveyance and distribution systems owing to past neglect of technological research on

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this subject. An in-depth review of the research programmes on irrigation and drainage before the creation of the International Programme for Technology and Research in Irrigation and Drainage (IPTRID) in the late 1980s indicated that irrigation research in most countries, even those with very large irrigation development such as China and India, was focusing on irrigated agriculture research and conventional engineering techniques, such as construction of large storage and diversion dams.

China is now a leader in the design and construction of Rolled Compacted Concrete (RCC) dams. China has extensive experience in the production and installation of geomembranes for lining of irrigation canals and has successfully developed on-farm water-saving techniques, such as the wet and dry intermittent irrigation of paddy. These techniques are now widely adopted in some regions.

2.1 On-farm modernization techniques

This topic will not be addressed in depth in this paper because of the extensive extant research by the private industry and by public research organizations. The private sector is very active in promoting water-saving equipment through international conferences and expositions such as those organized by the Irrigation Association in the United States.

It is important to note that in most countries the adoption of pressurized water-saving techniques at the farm level is occurring in areas supplied by groundwater, which provides the flexibility and reliability of water service required by these techniques.

The poor service of surface water distribution is a major constraint to the adoption of on-farm techniques. Only when farmers obtain a reliable and flexible water service will they invest in on-farm harvesting techniques, adopt higher production inputs such as fertilizers and shift from low value to higher value crops.

In Libya and Saudi Arabia, where groundwater is the main water source, sprinkler irrigation is by far the most predominant method, while in Cyprus, Malta, Jordan and the United Arab Emirates micro-irrigation is the most widely used technique, being practised on over half of the irrigated area. In Lebanon, sprinkler and micro-irrigation techniques are practised on more than 50 percent of the irrigated area. Contrariwise, in Turkey and Iraq where groundwater is not well developed, modern irrigation techniques have not been widely adopted. In Turkey, almost 94 percent of the total area is irrigated using surface irrigation methods (furrow, basin and border). In some Middle Eastern countries and elsewhere, irrigation modernization is understood as the conversion of poorly gravitated irrigation systems to pressurized counterparts, without considering the constraints imposed by the delivery system.

2.2 Canal lining

The standard technique to reduce seepage losses from irrigation canals is to line them with rigid construction materials, such as cast-in-situ concrete, pre-cast concrete panels or bricks. Research studies have shown that about 60 to 80 percent of water lost in unlined canals can be saved by lining. However field investigations have demonstrated that the efficiency of canal lining may decline rapidly over time, especially if construction standards are low. Lining may increase the total cost of an irrigation project by 30 to 40 percent compared to the cost of an unlined system. Before making such an investment there must be a clear understanding of the benefits to be obtained. High standards in design and construction are essential for long canal lining longevity.

The geosynthetics industry now provides long-term solutions to the control of seepage losses in irrigation canals. The industry has developed exponentially during the last 30 years. Applications in all civil engineering projects, including dam construction, drainage and flood control as well as irrigation schemes are considerable. The use of geosynthetics has evolved from the empirical approach of the 1960s to a well-developed science based on analytical studies and testing of materials. High-performance geomembranes made of different elastomer or plastomer materials are available for different applications, such as exposed or protected applications.

Unexposed geomembranes for canal lining have been used for a long time in China. However the now obsolete technology used until the mid-1990s — installing very thin overlapping unwelded sheets of polyethylene —

was able to reduce seepage losses by approximately 50 percent. In the late 1990s, Xinjiang Province adopted the modern technique of using geomembranes thick enough to be welded. It is estimated that annual water saved in the Tarim Basin via the use of this technique over about 500 km of large canals approximated 60 to 800 million m^3. The waterproofing material used was a 0.5-mm-thick geomembrane, composed of a proper mix of HDPE, LDPE and VLDPE. This material, sensitive to UV, was protected with cast-in-situ concrete, pre-cast panels, cobbles or earth.

Hunan Province has recently installed exposed geomembranes, about 2 mm thick, to rehabilitate aqueducts with severe leakage and physical deterioration.

Technologies have also been developed for special applications, such as for lining of existing canals under operation (concrete-filled mattresses) or lining with a minimum interruption of irrigation service (e.g. geocells, site-fabricated geocomposite).

The mattresses are laid in the canals under water and then filled with concrete mortar. This technique is commonly used for river and delta protection activities. It has been used for irrigation canal schemes in Indonesia and Islamic Republic of Iran.

The site-fabricated geocomposite is a technique developed by the chemistry industry in the United States; it involves the use of a geotextile impregnated with liquid polyurethane and additives. After a few hours, the hardened material is still flexible. The technique is increasingly being adopted by irrigation districts in the United States to carry out urgent repair on short sections of canals less than one kilometre long. Interruption of irrigation service does not exceed four to five days. However it has not been used yet for extensive lining of canals.

The industry has developed a "geocell" material consisting of a net of polyethylene cells of specific height. When laid on canal slopes, the tolerances for canal trimming can be reduced considerably, resulting in substantial time saving. Use of this material is still limited in irrigation schemes because of the cost.

While it is important for engineers who design hydraulics projects to be aware of the new possibilities offered by the geosynthetics industry, it is equally important to be aware of the need for careful calculation. Some design and construction aspects require special expertise, such as the selection of materials for a specific application with regard to variations of temperature, expected life, stresses during installation, stresses in service and thermal expansion–contraction.

If properly designed and installed, geomembranes and other geosynthetics can considerably reduce seepage losses from irrigation canals and consequently improve the performance of irrigation systems.

2.2.1 Modernization of the operation of canal irrigation systems

The concepts of canal irrigation modernization were and still are not well understood and adopted. Clemmens, the keynote speaker at the International Commission on Irrigation and Drainage (ICID) Congress in Beijing in September 2005, argued that "chaos" is inherent to all large-scale delivery systems. He defined chaos in the context of a small deviation in the upstream part of a canal system from a target delivery flow resulting in large variations in water delivery further down. He rightly argued that neither improved management nor water measurement are the answers to such chaos:

> *A good deal of effort was put into improved irrigation system management. Such efforts were marginally successful. I do not believe that improving management alone will significantly improve the productivity of these systems. It may result in small increments, but not in substantial gains.*
>
> *"Ideally water deliveries to all the users (or from one level to another level of management) should be measured and continuously monitored. This is cost prohibitive for most projects. However, it is difficult to develop effective management controls without appropriate feedback on operational performance. Water measurement is a key component of water control, but it is not sufficient for significantly improving productivity by itself.*

The difficulty of the operation of a manually operated system encouraged the development of automatic hydraulically operated gates. Modern automatic control of gates may have begun in the 1920s with the installation of automatically controlled-leak gates (known as Danaidean gates) in the Unites States. The Danaidean gates installed in the Turlok Irrigation District in California, built of hardwood, are still in operation nearly 100 years after their installation. The French industry developed a series of float-operated gates to maintain upstream (AMIL) or downstream constant flow (AVIO and AVIS) as well as constant flow modular distributors in the late 1930s. These gates are widely used in Mediterranean countries and in some projects in the Middle East, such as in Islamic Republic of Iran (Guilan) and Iraq (the Lower Khalis, Kirkuk).

Concurrently automatic flap gates were developed in the Netherlands to maintain a constant water level upstream.

Passive concrete structures, known as long-crested weirs were also developed to limit the variations of upstream water level by increasing the length of the weir. These passive structures do not meet the definition of automation by Burt.[2] They are designed to limit the variations of the upstream level and their design is highly versatile. They have been designed either in V or W shapes, oriented upstream or downstream, alone or in combination with undershot gates.

The development of these hydraulic devices has considerably simplified the operation of canal irrigation systems and reduced labour costs. The only adjustments of the gates are at headworks under upstream control and the openings and closings of the modular distributors. However there are some limitations.

The two possible canal control logics with local automatic hydraulic control are upstream and local downstream control. Upstream control requires the preparation of an elaborate irrigation scheduling based either on the individual farm orders or on considerable field and meteorological data collected by the operator and estimates of efficiency and time of transmission. Downstream control eliminates the need for preparation of an irrigation scheduling, but its application is limited by the slope of the existing canals and the feasibility of raising the banks of canals to convert them to level top canals.

Upstream control is the standard canal control logic in most irrigation systems. Operational losses, estimated at about 5 to 10 percent of the flow diverted into a canal under upstream control, are needed to provide a reliable service to the downstream area because of the uncertainty in some hydraulic parameters and unexpected changes in irrigation requirements. These losses are inherent to upstream control. Some additions to the infrastructure of existing systems can reduce operational losses, such as construction of compensation reservoirs and interceptor canals.

A feature of the local hydraulic control is that the target level is set once the gates are installed (by contrast to gates under local controllers, as discussed later). This could be a drawback if the transit capacity of the canal has to be changed. The cost of the float-operated gates is high compared to conventional gates — the weight of steel needed for the construction of the float, the counterweights, the leaf gates and other elements. However a simple investment cost comparison is not acceptable. Cost of operation and water saving should be included in a cost–benefit analysis.

2.3 Local (computerized) controllers

The aforementioned hydromechanical equipment for canal control developed by European countries was not adopted in the United States, possibly because of the difficulty in adapting it to the constraints of existing systems. The old design standards of the Bureau of Reclamation, which were widely introduced in many countries (for example in Turkey and Khuzestan in Islamic Republic of Iran) in the 1960s and 1970s, were based essentially on the use of manually operated undershot gates. Canal automation developed in the United States with the advent of electronics and progress in telecommunications. The first applications of local

[2] "Canal automation refers to a close loop in which a gate or pump changes its position/setting in response to a water level, flow rate, or pressure because that level/rate/pressure is different from the intended target value. Close loop means that the action is performed without any human intervention. The automation may be performed through hydraulic, electrical, electronic, or a combination of these means".

controllers occurred in the western United States in the late 1950s. These installations were electromechanical gate controllers to maintain a constant upstream water level at the cross-regulator. In the 1960s, attempts were made to maintain the water level downstream from the structure through local automatic control. As the water level sensors were distant from the control gate, and in most cases, upstream of the next control gate, communications were required. Local downstream controllers required better control logic to deal with the lag time between the gate and the sensor. Eventually electronics (Programmable Logic Controllers or PLC) replaced the electromechanical equipment. There are now many successful applications of local controllers. Applications include mainly control of flow at off-takes, and control of local upstream water level.

Local automatic control alone, whether it is actuated by hydraulic or electronic action, has the operational disadvantage that the field conditions are not continuously known by headquarters, unless a reporting system by field staff is established, which is hazardous in case of emergency.

2.4 Supervisory Control and Data Acquisition (SCADA)

Supervisory control consists of bringing system-wide information from remote sites to a single master station. Supervisory monitoring can give a water master the power to view the whole project without leaving the office. Supervisory control changes the target points of local controllers and empowers a water master to make rapid coordinated changes at key structures. Supervisory control was implemented in the 1970s on several irrigation systems, such as the Salt River Project and the Coachella Irrigation District. With further advances in equipment Supervisory Control and Data Acquisition (SCADA) has now spread to a number of irrigation districts in the Western United States, such as the Turlok Irrigation District, the Imperial Irrigation District and many others. Adoption of SCADA has considerably improved the performance of irrigation districts in the United States and other countries.

Few SCADA projects have been implemented in developing countries and many of them have failed for various reasons. The most critical phase in an automation project is implementation: Selection of the equipment, the integration of hardware and software components, installation and testing. Shortcomings in electronic/communications-based automation are possible at all stages: Design, implementation and operation, control algorithm limitation, poor integration of components, malfunctioning of equipment, lack of training of operation staff, lack of spare parts and poor maintenance.

A large SCADA project is presently under implementation in the Fergana Valley in Central Asia. This project consists of the simple automatic control of flows diverted to large canals from the Naryn River downstream from a cascade of power plants and remote monitoring of operation of three pilot canals. Some conditions for the successful implementation of the project are:

- The standard control equipment (level sensors, gate positions, PLCs) are produced by the local industry or imported — and not by researchers, as could be the case in some countries (Mexico).
- The integrator company has long experience in automation.
- Headquarters are in Kyrgyzstan and there are branches in other countries.
- Maintenance is contracted to this company on an annual basis.

The risk of failure of this project is the low understanding of the control logic and use of Programmable Logic Controller (PLC) keyboards, resulting in preference for manual control. A sophisticated centralized control system was installed in Uzbekistan early in the new millennium. Local staff generally use manual control because of lack of confidence in the complex control system.

It is strongly recommended to start with simple automation or SCADA projects and to expand progressively. However, risk of vandalism could preclude the adoption of any advanced technology.

The increased capacity of computers in the 1970s made it possible to develop simulation models to study channels under unsteady flow conditions. The well-known dynamic regulation of the Canal de Provence, providing irrigation water and raw domestic supply to a large area in southern France, is based on a large simulation model and a predictive method of water demand. Dynamic control was adopted for the King Abdullah Canal in Jordan, the pilot Majalgaon canal project in Maharashtra State, India and the 1 000 m^3/s Narmada Canal in India. Centralized control was also adopted for large water transfer systems in the United States, such as the California Aqueduct. Such complex systems are generally not used in irrigation systems.

3. Overall conclusions and recommendations

China, similar to other countries with large water resource development schemes, has demonstrated the capacity to adopt advanced technologies in design and construction techniques. China is even the world leader in the application of modern technologies, such as the construction of RCC dams.

In the domain of irrigation modernization at the system level, the adoption of new techniques to improve the operation and quality of water distribution is relatively limited. Adoption of these techniques requires a very intensively focused training programme for stakeholders at all levels (including planners, designers, contractors, project managers, field operators and members of water user organizations). Experience in other countries has shown the difficulty of technology transfer in water control. Designers strongly adhere to old standards and are not willing to change. Operators are accustomed to deeply entrenched practices. For example, they are not confident with automatic local control and shift to manual control once the specialists have left the project area. Users are often opposed to static long-crested weirs because the function of these devices was not explained. It is highly desirable to establish a local industry in canal control, which should also be responsible for maintenance of the equipment. This requirement limits the application of computer-based canal control technology in many developing countries.

Modern management practices at Jiamakou irrigation project

Zhang Xuehui[1]

1. Introduction

The Jiamakou Yellow River Diversion (JYRD) project is located in the southwest of the Yuncheng Basin, Shanxi Province. Belonging to the semi-arid zone, Yuncheng has a temperate climate with annual average temperatures ranging between 11.8 and 23.7°C, average rainfall of between 490 and 620 mm and non-frost periods of 186 to 235 days. Yuncheng City has a total population of 4.95 million, of which 3.51 million are rural workers. Covering an area of 14 000 km^2, Yuncheng has a total cultivated area of 584 900 ha (8.8 million *mu*) and the average cultivated area per capita is 0.14 ha (2.15 *mu*). With excellent natural conditions, Yuncheng has major potential for agricultural development but is constrained by chronic water shortages. The perennial average of total water resources in Yuncheng is 1.448 BCM — nearly 70 percent is overexploited groundwater. Available water per capita is only 267 m^3, at the bottom of the Shanxi ladder, and accounts for 12 percent of the national average of 2 234 m^3.

The JYRD project is the first large pumping project, with a 70-m-high lift, in the Yellow River Basin. This key project is located in Jiamakou Village, on the eastern bank of the northern course of the Yellow River. The project was started in 1958 and began to benefit local people in 1960. The project integrated water sources, water pumping and lifting and irrigation canals into a holistic scheme. The project has potential lifting capacity of 55 m^3/s (the current actual lifting capacity is 34 m^3/s); two pumping stations with 27 sets of equipment were built in Jiamakou and Xiaofan with a lifting capacity of 23.2 m^3/s. The designed irrigated area of the project is around 33 500 ha, covering nine townships from two counties (Linyi and Yongji), and a population of 250 000. Fruit, cotton and cereals are abundant in the irrigated area.

2. Modernizing irrigation scheme management

With adjusted industrial structure and cropping pattern changes in irrigation schemes, water demand from farmers has increased continuously. Therefore, how to improve the service to meet water demand and to increase water production is a major challenge for agricultural irrigation today.

On entering the twenty-first century, the 16th Plenary Session of the Communist Party of China created the considerable targets of "adhering to the concepts of scientific development, building a relatively well-off society in general, maintaining the balance between human beings and nature and advancing the principles of sustainable socio-economic development in the context of improved livelihoods and ecological balance". Under this paradigm, modernization of management has become the only option for the JYRD project, governed by new water control strategies that involve shifting from traditional water conservancy to modern and sustainable development methods that support growth through the judicious utilization of water resources.

Modernization of irrigation is an important feature of water conservancy. For the JYRD, we have upgraded scheme management by using advanced technology, decreasing the operating cost, improving irrigation water use efficiency and productivity and providing a better service to the farmers. In so doing, we achieved the planned management objectives of increasing farmers' income, developing the irrigation scheme and addressing staff welfare.

3. Essentials for modernizing irrigation scheme management

After years of practice, we have identified the following five essential factors for modernizing irrigation scheme management:

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[1] Director-General, Jiamakou Yellow River Diversion Administration Bureau.

3.1 Holding to key management principles

Our core values include respecting the staff, practising thrift, team working and putting the farmers' interests first. Such values are key to project management and motivate JYRD staff; they also enable staff to strive for excellent service, use resources carefully and maintain ecological balance.

3.2 Sticking to management objectives

Our mandate hinges on generating benefits for farmers, the project and staff. Increasing farmers' income is the primary objective; sustaining the incremental value of the project and maintaining facilities in good working condition are the second objective; and motivating staff (the mainstays of the project) is the third objective.

3.3 Establishment of better management and operation mechanisms

After liberalization, the management and operation mechanisms of the former system could not meet the demands of the new order. To address this situation, we provided each pumping station with clear managerial and self-supporting modalities and upgraded operational mechanisms to provide farmers with improved water supply.

3.4 Using advanced technologies

In a scheme with 500 000 *mu* of scattered irrigated area and thousands of farmers, it is impossible to supply sufficient, timely and efficient irrigation water to individual farmers without the support of advanced irrigation and information technology. In this regard the application of advanced technologies assures the achievement of management objectives.

4. The action procedures

Based on management objectives, we established five systems for management organization, water goods, project construction and maintenance, services and scientific evaluation, which cover all aspects from project construction to irrigation water management. Our achievements are described hereunder.

4.1 Organization

The management organization system was established to separate administrative affairs from business activities and to clarify duties and rights among staff.

4.1.1 Disaggregation of administrative affairs and business activities

In the transition to the market economy system, our service objective has shifted from the collective unit to individual households. Thus service management has changed from its original purely public service mode to a market-oriented quasi public service mode. After restructuring the organization of the former management system, the current administration bureau consists of four major sections: Administrative management, integrated affairs management, the water business unit and logistics service. The administrative section has standard control of institutional development; the nine water management stations are components of integrated affairs management; pumping stations, main, branch and tertiary canals act as water business units that are required to be financially self-sufficient; and irrigation experimental stations, information centers, communications stations, and Jiamakou Hotel are all logistic service units.

4.1.2 Simulating the enterprise mode

Pumping stations are the production units and main, branch and tertiary canals are the water-selling units. The farmers are the consumers of water. An irrigation water market has thus been established from the pumping stations to the farmers' fields. All farmers enjoy self-governing rights for their individual fields. The administration bureau addresses their fiscal affairs according to their achievements. Under this transparent water supply system, farmers have legal rights in the irrigation process.

Due to such "business" transactions, we arouse considerable enthusiasm, decrease operational costs and improve irrigation water productivity.

4.2 Water goods

The purpose of setting up a management system for water goods is to reduce water losses, consumption and irrigation costs and improve water productivity. To manage water goods, we have adopted three modern business management theories: Management of commodity (water) circulation, fiscal (water fee) circulation and information (water information) circulation.

4.2.1 Management of water circulation

Drawing up the schedule for irrigation water distribution: Before the irrigation season, the irrigation section will complete the detailed water distribution programme according to rainfall forecasts, cropping patterns, irrigated areas and irrigation quotas. Meanwhile, the irrigation section will assign water distribution tasks to every water business unit.

Supplying water according to farmers' demand: During the irrigation season, the management stations of main canals will collect information on water demand at 20.00 hours and then report it to the water-controlling center, which will determine the number of working pump sets. Pumping stations and main canals carry out water selling and buying through scientific measurement.

Scientific operation and rational distribution: Water operators from the main canals provide sufficient water to each second level canal safely and stably according to individual water-delivering capacity.

Flexible, stable and sufficient water supply: Obtaining the water from the next upper level canal, the head of the tertiary canals is responsible for supplying stable and sufficient water to the farmers. Parshall flumes are used between main canals and lateral canals and cut-throat weirs are used between branch and tertiary canals for water volume measurement. Every canal is equipped with accurate measuring facilities.

Information feedback: When the irrigation season ends, the irrigation management section will collect information on water diversion and distribution for each water management unit and information on water used by the farmers.

4.2.2 Fiscal management

According to national financial regulations, we have rules for fund collection and expenditure, which include the collection of water fees and expenditures.

Water fee collection management

- The head of each tertiary canal buys water tickets from the local township water management station before irrigation application; risk rewards are provided by the administration bureau.
- The head of each tertiary canal obtains the water at the canal turnout by handing the water tickets to those responsible for distributing water to the farmers. After the irrigation application, the farmer should sign for the exact water amounts to facilitate fee collection.
- After the irrigation application, the head of each tertiary canal prints out receipts for the water users at the township water management station, then collects water fees from the farmers via the water receipts.
- After collecting the water fees from the farmers, the head of each tertiary canal deposits the balance of water fees at the township water management station.
- Each township water management station transfers the water fees to the management bureau every ten days. Water fees are managed according to relative laws and regulations to avoid fund interception and appropriation.

4.2.3 Fund expenditure management

Fund expenditure management is twofold: (1) Expenditure by the managing units and (2) administration management. For the former, the expenditure amount is settled according to the actual achievement in the light of the contracted quota. For the latter, expenditure follows strict rules for planning management and approval procedures. The procedures are:

- Financial expenditure is managed according to plans with reference to income.
- According to the income from water fees and the principle of production first, the financial section makes all the expenditure plans, then reports to supervisors and the head of the administration bureau.
- Expenditure is made according to the approved plans.
- After expenditure, the undertakers submit the expense to the head of the unit for approval, supervisors and the head of the administration bureau.

4.2.4 Information management

Information dissemination aims to assist water goods and fiscal management. A suite of telecommunication networks supported by datasets and audiovisual productions has been established; the construction of information centers for Yuncheng management bureau, Linjin water control center and the Jiamakou control center for pumping stations has been completed.

The Jiamakou information center has seven components: a farm household management system, an automated data management system for pumping stations, an irrigation management system, a decision-making system for irrigation management, a water fee collection system, a project management system and an office automation system. Each system is independent but interconnected. Functions are described hereunder:

- *The farm household management system:* To create files for the farmers and water user accounts, to answer water fee inquiries via telephone and PCs, to print water fee receipts for water fee collection.
- *Automated data management system for pumping stations:* To automatically retrieve, display and relay operational data about machinery and observation stations; to realize the automatic opening and closing of water gates; to automatically manage breakdowns. This system plays a very important role in the safe operation and management of pumping stations.
- *Irrigation management system:* This system concerns details related to water business affairs and has five sections (pumping station management, main canal management, branch and tertiary canal management, measuring section management and integrated affairs management). The main task of this system is to record the water diversion and distribution of each unit, data collection and analysis and to fulfill each quota settlement, fee return and autogeneration of worksheets.
- *Decision-making system for irrigation management:* Scientifically analyse and determine the water demand of different crops and plots over alternate periods; to compare the water consumption of each water user unit in different periods; to calculate the crop water requirement and to develop a sound water irrigation programme.
- *Water fee collection system:* To print water fee receipts and provide financial reports.
- *Project management system:* To draw and revise the map of the irrigation area; to locate and describe the main infrastructure; to keep electronic files of schematics; to oversee network management of materials submitted to the project.
- *Office automation system:* To support on-line document reading and approval, network meetings, the storage of documents and files and Web mail.

All the data for the information system management must be entered into the computer via local terminals and then sent to the information center of the management bureau. After systematic collection and analysis, the information will be relayed to consumers.

4.3. Project construction and maintenance management system

The purpose of this system is to improve infrastructure capacity and to ensure the healthy and sustainable development of the irrigation system. This system has the following objectives:

- *Good project design:* For those projects in need of expansion, reconstruction and rehabilitation, the project engineering section and the water project designing section conduct a site inspection; subsequently they provide a technical design for the project according to design standards and demand, and finally report to senior management for approval.
- *Public bidding:* For approved projects, we invite public bidding in order to choose reputable construction units, according to regulations for water project bidding.
- *To strictly manage project construction:* To control investment, quality and speed and contract management, supervising units will conduct general supervision of the project. Representatives from the owner will coordinate and solve problems during construction.
- *To monitor the project strictly:* In the monitoring process, we conduct "self-inspection, interinspection and takeover inspection". After project completion, the relevant departments will conduct a general inspection on the design, construction and quality. When the project has been thoroughly inspected and accepted, it will become operational.
- *Professional routine maintenance:* After commencing operation, the project will be checked every season to ensure proper maintenance is in place. The head of the unit is responsible for keeping the surroundings tidy and clean and maintaining the facilities.

4.4. Management system for serving farmers

As consumers, the farmers enjoy legal rights to water use. This system also complements the Sunny Project[2] and improves the service level so farmers obtain water at reasonable prices. It has three components:

- To help farmers establish water users associations (WUAs) for management at the tertiary level. To regulate tertiary canal management to ensure the full optimization of project benefits.
- To guide farmers in scientific irrigation and conservation of water. Through weather forecasting, measurement of soil moisture content and irrigation scheduling for different crops, we train farmers to irrigate appropriately in order to maximize irrigation benefits.
- To implement the Sunny Project and reduce the farmers' burden. We try to avoid price hikes and made the water price public through enhancement of water measurement and the "water affairs public system".

The township water management station is responsible for the following activities:

- *Establishing WUAs and a tertiary canal management committee in the irrigated area:* The head of the committee is selected as the legal representative and is responsible for farmers' interests. The head of the management committee is responsible for employing irrigation managers for the tertiary canal who are responsible for the maintenance of the canal and farmers' irrigation.
- *Delivering sufficient water to farmers' fields:* Before the irrigation, the head of the tertiary canal will contact the next higher canal in the chain to determine the water release time and flow rate, and distribute the water to each farmer's field.
- *Supplying timely and sufficient water and carrying out an open water commodity system:* While distributing water to the field, the head of the lateral canal is responsible for implementing the "three publics and one to the farmer's field" to ensure the open water commodity system. The "three publics" are public water supply, water pricing and supply duration. The farmers record the quantity of water applied by signing in the field each time the irrigation is finished.

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[2] A training programme, first initiated in 2004 by six ministries. It aims to equip farmers with basic skills to help them find jobs in urban areas.

- *Establishing water users' accounts for the farmers:* After every irrigation application, the head of the tertiary canal completes the water consumption forms and delivers them to the township water management stations where operators enter all data into computers and print water use receipts.
- *Disseminating water information via a bulletin:* After delivering the water fee to the township water management station, the head of the tertiary canal will disseminate household water use forms via bulletins for public oversight.
- *Enforcing the law to ensure farmers' interests by establishing a public security and water affairs section and an irrigation inspection team:* During the irrigation season, the farmers can consult water information sources and hand in complaints or suggestions every day. Thus water abuse cases can be penalized, staff behaviour is regulated and farmers' interests are protected.

4.5 Scientific evaluation system

The purpose of this system is to identify and solve problems in project operation and management to improve irrigation scheme performance.

Through diversified review and assessment, quantification of each evaluation index, modernization of operating devices and standardization of the entire operation, water business units are analysed and evaluated. The values of evaluation indices are increased from the average standard of the previous three years.

The review and assessment methods are:

- Three evaluation indices: The reliability of water supply, the quota of each cubic meter of water and the coefficient of losses of every thousand tonnes per kilometer are calculated each season. Those units that cannot meet the standard will be fined by 15 percent of the overconsuming component and those that fall beneath the standard will be rewarded by 65 percent of the saving component.
- A rating system assesses project facility maintenance. According to project management and maintenance standards and evaluation criteria, we conduct a public appraisal of each water business unit with a total rating for each item of 5. The salary of maintenance staff is deducted by 5 percent if the rating is below 3 for one item, 20 percent if the ratings of three items are below 3 and 50 percent if the three items continue to remain below 3. It has been suggested that the tertiary canal management committee should dismiss the head of the tertiary canal if ratings are consistently low.
- At the end of the year, administration staff are reviewed and assessed.
- Comprehensive assessment indices will be applied to total annual social production — outputs and inputs — and an objective appraisal will then be made.

Some major assessment indices include:

Assessment indices for pump stations:

- The amount of water lifting.
- The flexibility of water supply.
- The sufficiency of water supply.
- The reliability of water supply.
- Cost of water per cubic meter.

Assessment indices for canals:

- The amount of water diverted to canals.
- Water conveyance efficiency.
- The flexibility, reliability and equity of water supply to the tertiary canals.
- Canal maintenance level.

- The flexibility and reliability of the infrastructure (regulation gates, division gates and flumes/weirs).
- Operational staff's qualifications.
- Internal management regulations.
- The availability of roads along canals.

Review and evaluation indices for administration units:

- Working objectives.
- Standardization of the construction.
- Degree of work.
- Policy implementation and participation in project activities.
- Training and education for staff.
- Comprehensive annual review and assessment.

Comprehensive assessment indices:

- Social benefits.
- Annual irrigation efficiency.
- Irrigation water productivity.

5. Initial modernization achievements

With gradual improvement and practice in the five systems, infrastructure capacity has been strengthened and service levels have improved in recent years — thus making an important contribution to local agricultural development, enhancing farmers' income and nurturing the rural environment.

5.1 Increasing farmers' income

With improved reliability of water resources and capacity of the pumping stations, the farmers receive punctual water supply. Data from 2005 showed that the annual average income of each farmer in irrigated areas reached 5 652 yuan, about twice that of other Yuncheng farmers.

5.2 Enhancing infrastructure capacity

After abstracting experiences and lessons learned from the Yellow River water diversion, we have solved water diversion problems by establishing the Wuwang floating pumping station. The expansion of Jiamakou and Xiaofan pumping stations has been finished and two new pump sets have been added, thus water-lifting capacity has increased from 9.5 m^3/s in 1998 to 23.2 m^3/s today. The actual irrigated area has increased from 12 333 ha (185 000 *mu*) to 20 000 ha (300 000 *mu*). The water use coefficient at the main and branch canals has increased from 0.70 to 0.82. The collection rate of water fees reached 100 percent for nine successive years and income increased from 10.24 million yuan in 1997 to 20.94 million yuan in 2005. Fixed project assets have increased from the original 40.94 million yuan to 230 million yuan today.

5.3 Relatively stable staff

Through the increase in benefits yielded by the irrigated area, the annual income of each staff member increased from 3 300 yuan in 1998 to 12 500 yuan in 2005. Since 1998, we have recruited 57 college and university graduates. Out of 543 staff, there are six senior engineers, 20 engineers, 45 assistant engineers, 28 technicians and 139 workers. With improvements in working condition and income, the administration bureau has become a solid unit, admired by many people.

5.4 Social benefits

Statistical data reveal that between 1960 and 2005 the gross agricultural production value of Linyi irrigated area reached 6.2 billion yuan, of which net water resource profits amounted to 2.48 billion yuan. In 2005, the gross value of Linyi irrigated area was 6.1 billion yuan with added value of 10.5 yuan per cubic metre of water. In May 2006, FAO conducted a five-day assessment of the irrigated area and made the following appraisal: "The overall irrigation benefits, water use efficiency and irrigation water productivity are all higher compared with other irrigated areas with the same conditions and lead the way in China and the Asia–Pacific region".

6. Major problems

- *Substandard management for tertiary canals:* Although WUAs have been established, unbalanced development and lack of technical and policy support have resulted in weaker management.
- *Water price reform is not complete:* Because of the relatively low state of the economy, the existing water price is below the cost. During wet years, there are insufficient funds for maintenance and staff salaries so government subsidies are needed.
- *Insufficient investment for tertiary canals:* Less than 40 percent of canals are lined, so leakage losses and higher irrigation water cost remain major problems for irrigation in some areas. The improvement of tertiary canals can hardly be expected to depend solely on farmers' investment. Investment by the government is needed.

7. Conclusions

Confronted by the demands incurred by a rapidly developing society, we acknowledge the need for responsible water conservancy to enhance societal stability, maintain natural resource balances and protect the environment. On the path to further irrigation modernization, we will address new water utilization concepts, develop new modes and improve water productivity by adhering to the scientific water control policy promulgated by the 11th Five-year Plan.

This forum will help us to analyse national and international experience and technology. Consequently we will be able to upgrade management of the JYRD and achieve sustainable development targets. In the next five years, we will try to expand the upgraded irrigation area by 267 000 ha (400 000 *mu*), enhance water conveyance efficiency at main and branch canals by 83 percent, tertiary canal conveyance efficiency by 95 percent, irrigation efficiency by 51 percent and maintain relatively high irrigation water productivity for the betterment of society in general.

A rapid appraisal procedure to assess the performance of irrigation systems: Lessons from the FAO Regional Irrigation Modernization and Management Training Programme in Asia

Thierry Facon[1]

1. Introduction

The Food and Agriculture Organization of the United Nations (FAO) has been calling for a massive retraining of engineers and managers in irrigation agencies, consulting firms and irrigation service providers in Asia (FAO 2002). The intention is to train these stakeholders on ways to design and operate irrigation systems economically for optimum performance and adequate service to farmers who aspire to improved socio-economic well-being, evolve toward more commercial forms of agriculture and face the challenges of globalization. Water resource management is now moving towards integrated water resource management in river basins and competition for water from other sectors is intensifying.

This emphasis on training and capacity building arose from: (1) The results of a large-scale evaluation of the introduction of modern water control and management practices (FAO 1999), which indicated that insufficient knowledge of proper options was a major reason for the mitigated success of irrigation modernization projects; (2) the disappointing performance of irrigation management transfer and participatory irrigation management projects, which was partly attributed to the failure of these reforms to improve service to farmers and insufficient attention to operation, design and other technical aspects (Barker and Molle 2005) of irrigation systems. Intensified and ongoing training programmes for professionals in the restructured irrigation agencies, consulting firms that provide advisory services to water users' associations (WUAs) and for the managers of WUAs and the technical staff that they may employ for operation and maintenance (O&M) of their irrigation schemes are now recognized to be an important condition for the sustained success of transfer programmes. An appraisal of initial conditions and performance of the systems to be transferred would allow both better design and strategic planning of physical improvements together with a definition of the service to be provided both by the irrigation service provider to WUAs and by WUAs to their members, with indications on ways and means to achieve these service goals and improve them in the future.

Over recent years, the FAO Regional Office for Asia and the Pacific has developed a Regional Training Programme on Irrigation Modernization. This programme aims at disseminating modern concepts of service-oriented management of irrigation systems in member countries in order to promote the adoption of effective irrigation modernization strategies in support of agricultural modernization, improvement of water productivity and integrated water resource management. FAO has developed training materials and detailed curricula, as well as specific tools for the appraisal of irrigation systems for benchmarking and the development of appropriate modernization plans for irrigation systems. The first training workshop under the programme was organized in Thailand in 2000 and since then Viet Nam, the Philippines, Nepal, Thailand, Indonesia, Malaysia, Turkmenistan, Pakistan, India (Andhra Pradesh and Karnataka) and China (in Hubei and Shanxi Provinces) have benefited from similar programme workshops on irrigation modernization and benchmarking. More than 700 engineers and managers have now been trained through the programme.

The programme is starting to have an impact in member countries. The Royal Irrigation Department of Thailand is using the programme's tools and methodologies for the appraisal of projects, has included the training workshops in its regular training programme and uses FAO's Rapid Appraisal Procedure (RAP) as a diagnostic tool for its Irrigation Sector Reform Program. In Viet Nam, a World Bank-funded investment project (the Vietnam Water Resources Assistance Project) has a large irrigation modernization component based on the concepts introduced through initial training at the project preparation stage, which was

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instrumental in the adoption of revised design criteria. The Department of Irrigation and Drainage (DID) of Malaysia has included the training programme and its tools in its Quality and Modernization Strategies: Proposals for modernization of national rice granary systems now have to be submitted to decision-makers based on modernization plans developed by system managers following their training and appraisal of their systems using the RAP. In China, the Ministry of Water Resources is considering using the RAP (with adaptations) for policy evaluation, while at the provincial level, based on experience in the Jiamakou system, Shanxi Province Water Resources Department is considering using the RAP as a sectoral management tool. The RAP has been adopted by the World Bank as one of the three elements of its holistic benchmarking methodology for irrigation systems. The training programme is advocated for agencies wishing to invest in the improvement of O&M of large irrigation systems in the World Bank's *Sourcebook for investment in agricultural water management* (World Bank 2005).

Providing the services needed by the farmers, now and in the future, is a considerable challenge for irrigation planners and managers. This paper proposes elements of synthesis, recommendations and conclusions based on the lessons learned from the FAO Training Programme, focusing on details and aspects of the systems that are not frequently analysed, from the appraisal of irrigation systems by the programme's trainees using the RAP, from their proposals for improvement of the systems and from the use of the RAP itself.

2. The Rapid Appraisal Procedure: Training programme and benchmarking

The RAP was originally developed by the Irrigation Training and Research Centre of California Polytechnic University in 1996–1997 as a diagnostic and evaluation tool for a research programme, financed by the World Bank, on the evaluation of impact on the performance of irrigation systems by the introduction of modern control and management practices in irrigation (FAO 1999). The conceptual framework of the RAP (Figure 1) for the analysis of the performance of irrigation systems is essentially that irrigation systems operate under a set of physical and institutional constraints and with a certain resource base.

The systems are analysed as a series of management levels, each level providing water delivery service through the system's internal management and control processes to the next lower level, from the bulk water supply to the main canals down to the individual farm or field. The service quality delivered at the interface between the management levels can be appraised in terms of its components (equity, flexibility, reliability) and accuracy of control and measurement; it depends on a number of factors related to hardware design and management. With service quality delivered to the farm and under economic or agronomic constraints, the system and farmers' management produces results (crop yields, irrigation intensity, water use efficiency); poor system performance and institutional constraints manifest negative effects.

Results are evaluated and compared among projects through a set of external performance indicators (Appendix 1), while constraints, factors influencing service quality, service quality at different levels and symptoms are appraised through a series of standardized internal process indicators (Appendix 2); Appendix 3 provides an example of a typical service quality indicator.

FAO had a technical programme to promote the modernization of irrigation systems. At a regional consultation in Bangkok in 1996, the following definition was proposed for the modernization of irrigation systems:

> *Irrigation modernization is a process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes with the objective of improving resource utilization (labour, water, economy, environment) and water delivery service to farms.*

The lessons learned from the World Bank's research project and the RAP itself were considered by FAO to be important elements to be included in the Regional Irrigation Modernization Training Programme; the Irrigation Training and Research Centre (ITRC) developed more user-friendly versions of the RAP for use by the programme's trainees.

Benchmarking is defined as a systematic process for achieving continued improvement in the irrigation sector through comparisons with relevant and achievable internal or external goals, norms and standards. The overall

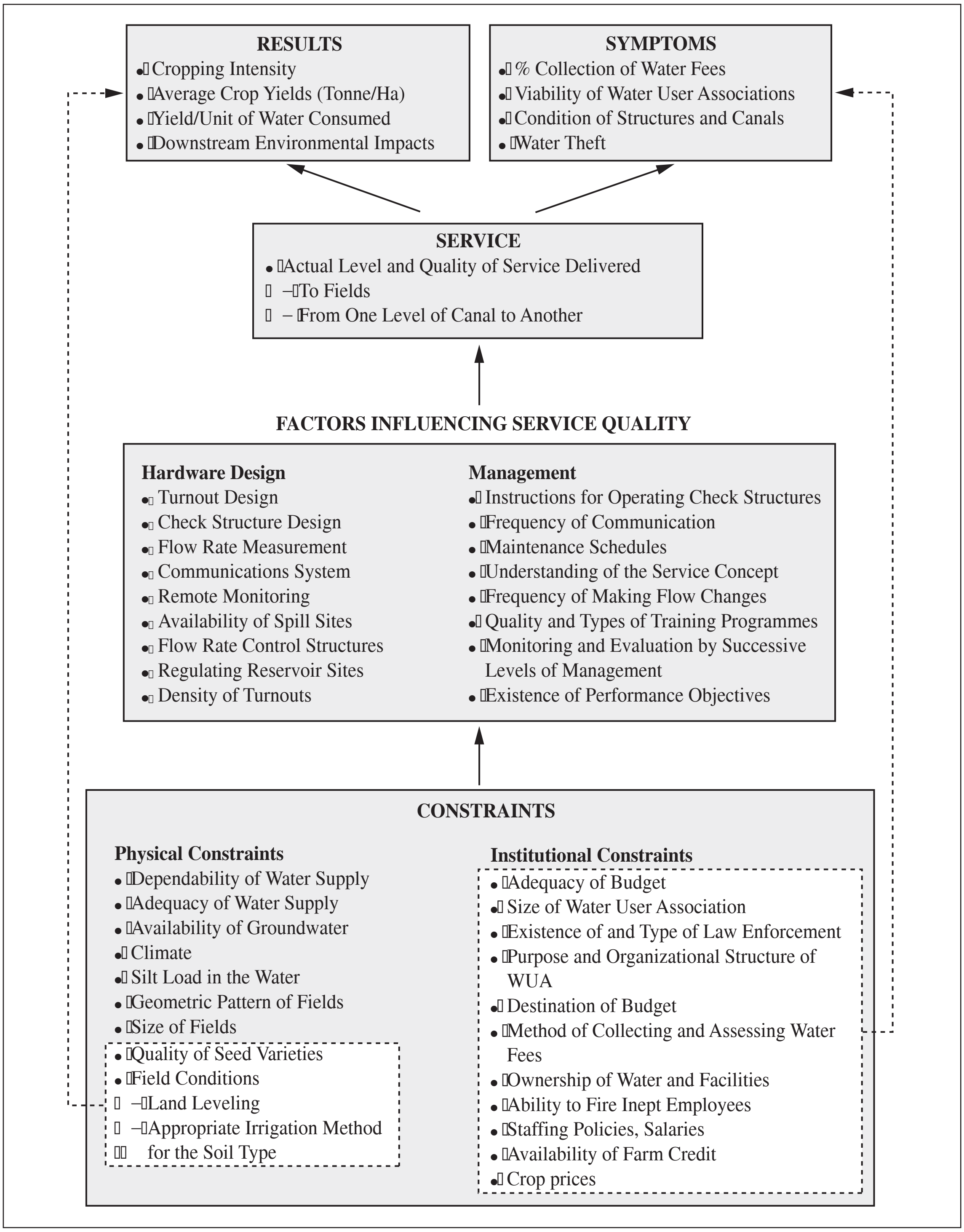

Figure 1. Conceptual framework for the Rapid Appraisal Procedure

aim of benchmarking is to improve the performance within an irrigation scheme by measuring its performance against its peers and its own mission and objectives. The benchmarking process should be a continuous series of measurement, analysis and changes to improve the performance of the schemes.

The evaluation and analysis stages of the "holistic" benchmarking promoted by the World Bank form the three legs of the benchmarking stool: Evaluation of technical indicators (both internal and external); appraisal of the system processes; and evaluation of service to users and their satisfaction with that service. The RAP, which was included as a component of the holistic benchmarking, concentrates on evaluation of the system processes and evaluation of the service at all levels in the system, from water supply to the scheme to the farm; it also assists in evaluation of the IPTRID benchmarking indicators, as the successive versions of the

RAP took care to use the same project descriptors and performance indicators — to the furthest possible extent — as the International Benchmarking Programme.

However, for benchmarking to go beyond the measurement and analysis stages and on to the implementation of changes and improvement stages, there must be significant acceptance by project personnel. Data collection and analysis are thus incorporated into a training programme that integrally involves local management and O&M staff. Staff members learn the concepts of modernization and are provided with a toolbox of options; they then evaluate their own project with the RAP. At the end of the training, internal and external indicators are developed for the project and the local staff members develop a modernization strategy and a priority list for changes in software and hardware. These are based on the internal process and service indicators, which appraise all factors that affect system performance and service delivery in a systematic and standardized manner in order to improve the specific characteristics of service delivery at specific levels and to achieve improvement objectives, defined by the external performance indicators. The external performance indicators (the IPTRID benchmarking indicators are essentially external performance indicators) allow the comparison of a project's performance with its peers and identification of possible objectives in terms of productivity, efficiency, economic and environmental performance, but do not provide assistance in identifying specific changes in processes and hardware to improve performance. This is the essential role of the internal process indicators.

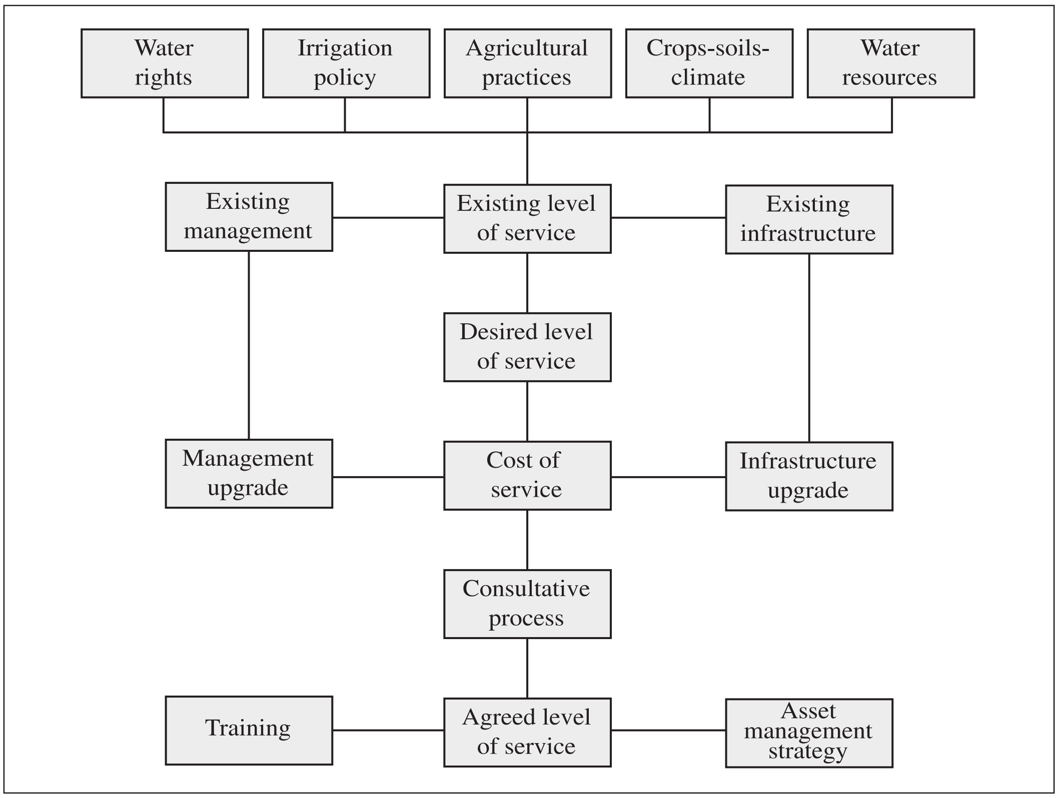

Figure 2. Management process for existing irrigation and drainage schemes managed with a service orientation (from Malano and Van Hofwegen 1999)

The management process for existing irrigation and drainage schemes managed with a service orientation, as proposed by Malano and Van Hofwegen (1999), is essentially a strategic planning and management process for a service organization.

3. Appraisal of the irrigation systems[2]

3.1 General findings

All irrigation systems appraised during the Regional Training Programme were large-scale rice-based systems, with the exception of the Jiamakou system in Shanxi Province, which will be addressed later. They were typically designed for supplementary irrigation of rice during the rainy season (with the exception of Turkmenistan, which has a desert climate). They are publically managed in a supply-driven mode. WUAs have been created in a number of countries but they do not play a meaningful role in the management of the systems. The systems are generally in a poor condition due to insufficient maintenance and provide poor service to farmers. Service provided by the main canals to the secondary canals and command areas is generally unreliable and inequitable, with the exception of the Malaysian and Chinese systems. Water level control in the canals is poor and a main factor in poor service delivery. Some systems had not received support for many years, while for others, substantial investment had been completed recently or was under way.

Design standards and operation have not changed in many countries for 20 to 30 years (Plusquellec 2002). The specific flow rates of the canals are calculated for supplemental irrigation; they are therefore quite small, and decrease from the main canals to the lower level canals. This does not allow flexibility of operation and large variations in flow rates. It is a particular constraint when farmers wish to synchronize their farming activities for mechanization and thus need large amounts of water for land preparation at the same time. Cross-regulators are, with a few exceptions, manually operated underflow structures, in combination with underflow off-takes, and generally very sensitive to fluctuations in water supply. In the Philippines, duckbill weirs have been introduced for water level control. However, most of them have been vandalized as the systems have large variations in their water supply. During shortage periods, the upstream off-takes receive their allocation until available flows are depleted and downstream off-takes are cut short. In some cases, off-takes are of the overflow type (Rominj gates in Indonesia), which exacerbates fluctuations of flow rates into the minor canals. Gates are rarely calibrated. The most common measurement method for flow rates is the orifice formula through (non-calibrated) gates. Other measurement devices have been introduced (broad-crested weirs), but typically they are poorly designed (too broad) and inaccurate, or submerged. Recirculation of drainage is practised in many schemes, but none is equipped with buffer or regulating reservoirs.

Operation generally follows a seasonal schedule which is adjusted on average every week, usually following qualitative assessments of demand by managers or requests by farmers. Typically, main structures are operated three times a day according to a set schedule, very often following instructions from a central office on gate positions. Although system managers often issue instructions on flow rate targets at each off-take, these are rarely followed and most field operators adjust gates based on water levels in the canals. Farmers often operate the gates themselves and operators and managers have capitulated to this situation. A typical response to this lack of discipline is the "rotational supply": Water levels are raised in canal reaches during "on rotation" periods and lowered during "off rotation" periods. Near-farm and on-farm infrastructure is underdeveloped. The introduction of command area development in the structured design concept or proportional flow division as an alternative to previous fully gated distribution network designs has not been successful. The systems are immediately subverted by the farmers.

Low-cost pumping technology and energy subsidies have allowed farmers to free themselves from the constraints of poor canal system performance or inadequate scheduling. This is done through groundwater pumping, illegal pumping from the canals, water scavenging or subversion of system policies and obtaining more reliable or frequent supply, switching to other crops and more effective on-farm water management strategies and techniques. Conjunctive use is not managed by anyone but usually allows farmers to adopt highly productive farming systems.

General management policies are typical of public institutions in the region, with few effective systems for rewarding or sanctioning performance. Field-level operators are often very poorly paid and it is difficult for

[2] A number of technical completion reports of the training workshops organized under FAO's Regional Training Programme, the programme's training materials and the RAP (in several regional and international languages) are available on FAO's Web site dedicated to the modernization of irrigation systems: www.watercontrol.org.

management and engineers to control how they actually operate the structures, which often differ from official rules and policies. How structures are actually managed is often directly responsible for the instability of the system. In the Sunsari Morang (Nepal) system, main canal operators, when trying to provide a target flow rate into a secondary canal, make an initial setting at the off-take of the secondary canal, then operate the cross-regulator of the main canal to lower or raise the water level in the main canal to adjust the flow rate into the secondary canal. If they have raised the water level in the main canal too much, they then open a safety structure to divert the "excess" water supply into a drain. This example, while extreme, illustrates the importance of all details of canal operation and of instructions to operators.

The administrative setup of the operating agency frequently hinders effective operation. In Thailand, the responsibility for the operation of long canals is divided into reaches under the control of different O&M projects which follow district boundaries. While water allocation is officially to each secondary canal, in practice there is a flow rate target at the interface between each project. As a result, the projects focus their energy on disputes on flow rates at these interfaces, operate the cross-regulators as flow control structures (creating water level fluctuations in the main canals) and neglect flow rate targets into the secondary canals, which thus fluctuate wildly; no specific office is responsible in case of water deficit in the lower reaches of the main canals. While project managers frequently integrate into their operation plans water supply to other users (municipalities, industrial customers), none of the projects appraised has specific environmental targets or goals.

Proposals and ideas from the training workshop trainees for improvement of their systems (and project proposals prepared by local consulting firms) — prior to the training — usually followed a standard menu of rehabilitation after prevailing standard designs, transfer of O&M costs to farmers and substantial investments in rigid canal lining. The introduction of SCADA systems and information technology is frequently considered or already at an early stage of introduction. However, details on selection of sensors or of control logic are often inadequate.

System managers sometimes have effective monitoring and evaluation systems in place but they are rarely used for immediate feedback for operation. Flow rates at spills and in drains are not monitored and managers do not have a proper water balance and estimation of the system's efficiency (with the exception of Malaysia thanks to DID's national benchmarking programme). There is however a gradual shift to performance-oriented management and the definition of performance indicators (Thailand). However, norms and budget allocations are often uniform nationally but do not reflect the constraints and potentials of projects, which may vary significantly across projects (e.g. the Philippines). Some projects (the Philippines) are piloting demand management with the introduction of volumetric water pricing. However, investment in the upgrading of the systems has not been geared towards improving control to customer WUAs, and proposed volumetric rates, based on current service fees, are not likely to yield expected water efficiency gains (de Fraiture and Perry 2002; FAO 2004).

In summary, the level of chaos (difference between stated policies and actual policies) and of anarchy (subversion of policies) varies from system to system, but is generally high, particularly at the lower levels of management. Recent investments following standard standards or investment strategies (command area development) have poor results in terms of performance, control and service. While lack of discipline and institutional issues contribute greatly to this situation, many of the problems can be traced to:

- Problems in initial design.
- Exporting of design concepts outside their area of validity.
- Difficulty in controlling and operating the systems.
- Layouts with confused hierarchies.
- Serious flaws in operation strategies.
- Inconsistencies between operating rules at various levels.
- Inconsistencies between operating rules and farmers' requirements.
- Changes in farmers' requirements not reflected by changes in system policies.
- Poor quality of water delivery service to farms.
- Lack of flexibility at all levels.

In this respect, irrigation planners, understood as central agency staff in planning and design branches, and irrigation managers, understood as system level field staff in charge of system operation, are two different groups. The former are not necessarily aware of the specific difficulties that managers face every day. Planning and design procedures, as well as terms of reference for consulting firms that are frequently assigned the tasks of planning and designing system improvements, are typically not centred on the concerns of managers and farmers. Participatory design procedures are progressively being introduced, but they frequently focus on details such as layout of the canal networks or positions of the off-takes, rather than on more general (and more important) issues of service and performance objectives and design criteria.

3.2 A Chinese exception?

The RAP results of the Chinese projects (Zhanghe in Hubei and Jiamakou) are in sharp contrast with projects in other countries. System efficiency, water productivity and service are very high compared with systems in Southeast Asia. While Zhanghe is essentially a rice-based system, it differs from other appraised systems by its “melon-on-the-vine” design, characterized by many buffer reservoirs, at all levels, connected to the system. The Jiamakou scheme pumps water from the Yellow River for an arid province; it has been converted rapidly from a wheat system to a commercial system dedicated to apple orchards, with a major challenge related to silt load in water supply. Both systems have benefited from modernization in recent years and are currently not operated under upstream control. Cross-regulators are not used for maintaining constant water levels in canals. However, what distinguishes these systems from their counterparts is not their technical features (infrastructure is not essentially better than other projects) but their management. The systems provide water delivery on an arranged volumetric basis to the heads of WUA canals, and charge water on a volumetric basis to farmers.

An additional feature of Jiamakou management is the model of “business units” introduced for management: Pumping, main canal water delivery and lower level distribution are organized into “business units” with performance targets which practically translate into financial incentives to staff. Before the RAP (May 2006), these financial incentives were related to efficiency of conveyance and distribution. As an outcome of the RAP, management objectives have been revised to include service standards, which have been translated into financial incentives.

For both projects, the authority of managers to effect and implement change seems to be much higher than in higher countries. In Jiamakou, action is immediately taken. In the four months following the RAP, the Jiamakou manager organized additional training and working groups to analyse RAP results and provide recommendations for areas where service indicators had been lower than expected. He has revised his management objectives and incentive systems and implemented a programme to improve water measurement devices at the heads of field ditches, where water is measured for volumetric charging.

For both systems, management objectives related to service improvement (improving lower level service in Zhanghe and improving field level flexibility for Jiamakou) will imply using cross-regulators to maintain constant water levels, with the objectives of improving flow rate control at all levels of the systems. Technically and for management, the main issue for Zhanghe is to re-establish coordination among the multiple level reservoirs, which was disrupted by decentralization of water management; for Jiamakou, the main issue is to utilize in-line storage to buffer the gaps between water supply by pump sets and demand, whose variations will increase with enhanced flexibility, as heavy silt loads do not allow for off-line buffer storage.

For both systems, reducing service costs is a paramount objective. While Jiamakou views financial incentives to staff as the key to improving performance, the one variable management cannot easily control is number of staff: The strategy is therefore to redeploy this staff over a larger service area in a future expansion phase.

4. The challenges

Expansive surface irrigation systems in Asia suffer from a legacy of poor design, degraded infrastructure, poor management and stagnation in the face of rapid transformations in agriculture and pressure on their water supply. The challenge is to transform these systems from supply-driven to demand-driven responsive systems; improve their financial, environmental, technical and service performance to significantly increase control, reliability, equity and flexibility (to allow them to adapt to changing or more variable water allocations); and enable farmers to boost agricultural and water productivity and be more responsive to market opportunities by adopting new and diversified water management practices on their farms. Water-related system level objectives need to be determined on a case-by-case basis based on water balances and basin level considerations on the one hand and agriculture-related service objectives on the other.

Climate change combined with competition from other sectors will entail not only increased variations in rainfall and longer dry spells during the growing seasons, but also increased variations in water allocation to the schemes from season to season; agriculture will most likely be considered the residual water user after priority needs from other sectors have been met. This will call for flexibility in changing operational policies from year to year and increased farmers' participation in co-management of the systems.

However, in practice, existing water allocations and their future evolutions are often difficult to anticipate for irrigation planners and managers, as the present systems of administrative or de facto allocation are yet to evolve into river basin allocation and rights systems. Furthermore, managers as well as river basin planners very rarely have accurate and operational information on irrigation system efficiencies. While generally system achievements in terms of service quality are overestimated by management, system efficiencies are usually underestimated, both by managers and by agency level planners.

In addition, thanks to recent international and national efforts for envisioning strategic processes in the water sector, there is a general notion of the future landscape of agricultural water management. In practice, these strategies are not sufficiently detailed for planners and managers to visualize the practical changes that would be required to meet future water-related and agriculture-related challenges, the basis of which would be an analysis of services required by farmers in the future. An exception is Malaysia, where strategic-thinking processes have been adopted for a relatively long time and where DID has adopted specific performance targets and goals both for rice and for water management performance and where system level, institutional and farm level changes are viewed holistically in a transformational modernization process. A second exception is China, where, at national, provincial and system levels (for the RAP-trained schemes), policies at all levels are, as in Malaysia, clearly articulated on all aspects and, at system levels, economic as well as technical targets are specific and allow managers to translate them into service performance objectives and consider details of technical and managerial options for change.

Modernization proposals for the irrigation systems that were appraised, prior to the training workshops, usually failed to establish a linkage between system level objectives and proposals and stated objectives for the introduction of improved or innovative irrigation technologies at the farm level, or between new performance objectives and proposed reform of the management and institutional setup. Structured design, proportional water division and rotational supply are not compatible with new water-saving technologies developed for rice, which require frequent or on-demand irrigation water delivery. Some designs and operation concepts which seem to allow rice to reach its yield potential (Japan, Republic of Korea, Southern China's melon-on-the-vine design [Plusquellec 2002; Barker and Molle 2005]), were not represented in the sample of projects appraised in the Regional Training Programme; they are however viewed with increased interest by irrigation professionals. At the institutional level, the challenge is to develop new frameworks that can manage the complexity of the hydrological cycle, the multiple roles of irrigation systems and deliver irrigation and drainage service to farmers in a responsive, accountable and efficient manner.

Financing these activities would require considerable investments; rice prices are expected to remain low in the medium term and present financing arrangements do not cover O&M costs, let alone investments in upgrading of management capacity and infrastructure. However, increasing climate variability may increase the profitability of irrigation systems by reducing the risk of crop failure. The investment strategies of the countries in the region should have clear strategic objectives, whether production objectives concentrating on areas with competitive advantage (Malaysia for instance has this strategy and China has clear strategic objectives for water-saving irrigation) or poverty reduction and food security objectives targeting marginal systems. In these circumstances, it is imperative that increased attention should be paid to the quality and type of investment. At the policy level, the challenge is to align and harmonize water and irrigation policies with agricultural and environmental policies and integrate them into overall socio-economic development policies.

5. Response options

Water management response options need to explicitly address scale issues (farm, irrigation system and basin level institutions, law, policy and supporting infrastructure). A system's approach is essential to determine water balance-related objectives and water management strategies to achieve them. These strategies and changes should aim at improving water control, equity, reliability and flexibility of service to give farmers water management and crop choices.

Improvement strategies should be supported by strategic planning and management approaches with a service orientation (Malano and Van Hofwegen 1999). Participatory planning and design processes would assist in focusing management goals on farmers' needs. This would require increased decentralization of irrigation bureaucracy towards system managers and farmers' representative institutions.

Previous irrigation modernization projects have been partly successful at best but better options and strategies now exist. Major options include conjunctive use of surface and groundwater, recirculation of drainage, buffer reservoirs at appropriate levels in the systems, improved design of control structures, investment in drainage, operation and ordering procedures, piping of near-farm delivery and intensification of irrigation system management. Feasible and field-tested options exist. The gap is in capacity building of the irrigation profession and a critical action is the revision of design standards (Burt and Styles 1998; Plusquellec 2002; Facon 2002, 2005).

The Regional Training Programme has shown that when irrigation planners and managers are presented with these options, which they were not aware of, and furthermore, when they work together in developing proposals based on a detailed appraisal of the systems, they enthusiastically embrace them: The irrigation modernization plans that trainees prepared at the conclusion of the training workshops differed very significantly from their plans prior to the workshop. These plans included new technical options (in particular, buffer storage was seen as a powerful design feature) and proposed balanced investment in upgrading the capacity of management, farmers and in infrastructure, and improved communication and mobility for operation staff. Planned investment in infrastructure focuses much more on control and measurement as a priority. Plans also typically included as priorities changes in instructions to field staff for operation of control structures, changes in internal organization, improved procedures for ordering of deliveries and an initial focus on restoring and improving water level control in the upper levels of the systems as prerequisites for further improvements and investments in the lower levels. The programme has also shown that, as in Jiamakou, when managers have the authority to implement change, they do so.

Information and control technology and software are now robust and available off-the-shelf; moreover costs are decreasing daily. Their introduction through careful strategies would make an important contribution. A priority often found in the trainees' proposals is the remote monitoring of spills, drains and flow rates at major off-takes.

A business approach to institutions is key to the future sustainability of irrigation systems, in the sense that institutions should be tailored to deliver specific performance goals, in addition to governance and representation goals, and should generally improve service orientation and accountability, move towards decentralized management and reflect the diversity of stakeholders and water uses. Models of farmers' organizations may need to change towards professionalized institutions that can provide new ranges of delivery and other services and reduce transaction costs for farmers, as labour costs are increasing and labour and management shortages are expected. Options for overhauling public management institutions include financial autonomy, incorporation, professionalization, public–private partnerships, privatization and transfer to farmers' organizations. New promising models are emerging in China and other countries.

New financial instruments are required to cover not only O&M but also upgrading of management and infrastructure assets at all layers of agricultural water management, from farms, to WUAs, to system-level irrigation service providers and the river basin. Public investment support will still be needed to assist the transformation of systems and institutions in their transition from the present condition towards more agile and performing systems. This strategic investment may not be more expensive than previous infrastructure rehabilitation or canal lining programmes.

Further work is needed by international and national research on interactions between design standards, operation strategies, service level and water pricing. Volumetric delivery/pricing at the tertiary level is an achievable medium-term objective for gated systems provided that they are modernized (e.g. Viet Nam, Thailand) and is indeed achieved in the Chinese systems appraised (even if the current focus on volume delivery needs to address better control of flow rates as well in the future). Systems based on proportional flow division may well limit options to flat rate area-based or crop-based irrigation charges if users cannot have control over water deliveries and pre-empt the long-term goals of volumetric water pricing. The role of financial incentives (for management, operators, farmers) deserves additional attention.

For rice-based systems, policies and investments in the future need to be rice-aware rather than rice-centric (FAO Regional Strategic Framework 2005). Aligning water and irrigation strategies and policies with agricultural and environmental policies and overall socio-economic development policies can be facilitated through the dissemination of strategic planning and management and more inclusive policy development approaches (ESCAP 2004).

Finally, system management needs to move away from the generation of both positive and negative externalities by accident and from development of autonomous farmers' responses — to deficiencies in performance or inadequacy between farmers' demands and management objectives — to explicit management of multiple roles. There should be greater recognition of farmers' services and of their contributions to overall efficiency and productivity, for instance by pumping (recycling of drainage or conjunctive use) and of the costs thus incurred to them. A search must be conducted for the most practical, economical options on where, how and at which levels (main system, intermediate distribution, farmers, conjunctive use) to locate improvements for service delivery.

6. Conclusion

The challenges faced by irrigation planners, managers and farmers in Asia are numerous and complex. Uncertainties abound but the uncertainty itself is a positive item of information available for planners and managers to consider in the decisions they have to take today to face the challenges of tomorrow. Irrigation systems and their management have to evolve towards flexibility to adapt on a continuous basis to face increasing variability in water supply, climate and markets.

The main lesson from the FAO Regional Modernization Training Programme is paradoxical: The challenge is both under- and overestimated. *Underestimated,* because in the recent past there has been excessive reliance on policy reform, institutional reform, improved control technology, economic incentives and instruments for on-farm water management as measures to single-handedly deliver improved performance or service. The detailed appraisal of the irrigation systems, which were investigated through the Regional Training Programme, indicates that a complex and articulated mix of changes in all these fields would in fact be required. *Overestimated* because there is considerable potential for significantly improving system performance and service with the adoption of simple and low-cost measures, provided that an increased focus on all details of operation, management and design is adopted, and that planners and managers are aware of better options that are now available.

This does not mean that far-ranging and comprehensive reform or substantial investment will not be needed. This does mean that it is possible to initiate a process of transformational change with immediate benefits to farmers, in terms of service, and managers, in terms of ease of operation, which will allow the necessary reform agenda and investment programmes to be more strategically focused, achievable in a realistic step-wise approach, more easily implemented, acceptable to the various stakeholders and able to adapt to rapidly changing circumstances.

It has been argued that the RAP cannot be considered as performance benchmarking on the grounds that it focuses on planning investment in modernization of water control infrastructure, requires well-trained and experienced engineers, does not lend itself to regular application for many schemes and does not use comparison, over time and between schemes, as the basis for identifying performance gaps and planning improvements. In reality, the RAP uses comparison over time and between schemes as explained earlier, assesses all processes of management and operation as well as hardware and can be and is applied over many schemes (Thailand, Viet Nam, Malaysia). It can therefore be a useful and critical component of a national benchmarking programme aimed at improvement of sectoral performance if used at the inception of the programme when system managers develop their strategic plans or system upgrading plans, or to evaluate the impact of improvement projects, as is the case in Malaysia (in the near future China and Karnataka will follow suit). It does require well-trained and experienced engineers. Any significant improvement in the sector's performance in Asia will require well-trained and experienced planners, designers, managers and operators. For this reason, FAO and national irrigation agencies (e.g. the Royal Irrigation Department of Thailand, the Department of Irrigation and Drainage of Malaysia, the Karnataka Water Resources Corporation and soon the Shanxi Water Resources Department and the Ministry of Water Resources of China) will introduce the RAP within a training programme where trainees appraise their own systems with the support of a team of expert appraisers and trainers from the central office.

Furthermore, it has been affirmed that the benchmarking process will only be applied where managers "embrace the goal of pursuing best management practices within a service oriented management system" and that this implies a focus on the quality and cost-effectiveness of service delivery. This is the most original feature and central message of the RAP. In addition, by appraising service quality at all levels of system management and concentrating on service interfaces between the different levels, the RAP facilitates the taking into account of the objectives and concerns of the operators at all levels, from the upper level managers to the WUAs, which may exist in the system, to the farmers who receive services from them. The Jiamakou example shows that managers determined to improve management performance adopt the RAP precisely for this reason and, following the RAP, refocus management on service objectives.

Future development of the tool will focus on developing additional indicators to better address drainage and water disposal services, as well as the multiple roles provided by the irrigation systems and cover a broader typology of irrigation systems. FAO will cooperate with the Chinese National Committee on Irrigation and Drainage and Wuhan University to develop a new version of the RAP.

MASSCOTE (Mapping of System Services for Canal Operation Techniques), another tool, is also under development and has already been successfully tested in Nepal and Karnataka. Its objective is to provide a step-wise approach for managers to improve operations for cost-effective improved service delivery. This methodology will be introduced to Shanxi Province in 2007.

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Appendix 1. RAP external performance indicators

Item description	Units
Stated efficiencies	
Stated conveyance efficiency of imported canal water (accounts for seepage and spills and tail end flows)	%
Weighted *field* irrigation efficiency from stated efficiencies	%
Areas	
Physical area of irrigated cropland in the command area (not including multiple cropping)	Ha
Irrigated crop area in the command area, including multiple cropping	Ha
Cropping intensity in the command area including double cropping	none
External sources of water for the command area	
Surface *irrigation* water inflow from outside the *command area* (gross at diversion and entry points)	MCM
Gross precipitation in the irrigated fields in the command area	MCM
Effective precipitation to irrigated fields (not including salinity removal)	MCM
Net aquifer *withdrawal* due to irrigation in the command area	MCM
Total *external* **water** supply for the project – including gross ppt. and *net* aquifer withdrawal, but excluding internal recirculation	MCM
Total external irrigation supply for the project	MCM
"Internal" water sources	
Internal *surface* water recirculation by farmer or project in command area	MCM
Gross *groundwater* pumped by farmers within command area	MCM
Groundwater pumped by project authorities and applied to the command area	MCM
Gross total annual volume of project authority irrigation supply	MCM
Total groundwater pumped and dedicated to the command area	MCM
Groundwater pumped by project authorities and applied to the command area, minus net groundwater withdrawal (this is to avoid double counting. Also, all of net is applied to this term, although some might be applied to farmers)	MCM
Estimated total gross internal surface water + groundwater	MCM
Irrigation water delivered to users	
Internal authority water sources are stated to have a conveyance efficiency of:	%
Delivery of *external* surface ***irrigation*** water to *users* — using stated conveyance efficiency	MCM
All other ***irrigation*** water to users (surface recirculation plus all well pumping, with stated conveyance efficiencies, using 100% for farmer pumping and farmer surface diversions)	MCM
Total *irrigation* water *deliveries to users* (external surface irrigation water + internal diversions and pumping water sources), reduced for conveyance efficiencies	MCM
Total irrigation water (internal plus external) — just for intermed. value	MCM
Overall conveyance efficiency of project authority delivered water	%
Net field irrigation requirements	
ET of irrigated fields in the command area	MCM
ET of irrigation water in the command area (ET — effective precipitation)	MCM
Irrigation water needed for salinity control (net)	MCM
Irrigation water needed for special practices	MCM
Total NET irrigation water requirements (ET— eff ppt + salt control + special practices)	MCM

Item description	Units
Other key values	▯
Flow rate *capacity* of main canal(s) at diversion point(s)	cms
Actual peak flow rate of the main canal(s) at diversion point(s) this year	cms
Peak NET irrigation requirement for field, including any special requirements	cms
Peak GROSS irrigation requirement, including all inefficiencies	cms
ANNUAL or one-time external INDICATORS for the command area	▯
Peak litres/sec/ha of surface irrigation inflows to canal(s) this year	LPS/ha
RWS: *Relative water supply* for the irrigated part of the command area (total external water supply)/ (field ET during growing seasons + water for salt control — effective precipitation)	none
Annual ***Command Area Irrigation Efficiency*** [100 x (crop ET + leaching needs — effective ppt)/ (Surface irrigation diversions + net groundwater)]	%
Field Irrigation Efficiency (computed) = [crop ET — effective ppt + LR water]/ [total water delivered to users] x 100	%
RGCC: *Relative Gross Canal Capacity* (peak monthly net irrigation requirement)/ (main canal capacity)	none
RACF: *Relative Actual Canal Flow* (peak monthly net irrigation requirement)/ (peak main canal flow rate)	none
Gross annual tonnage of agricultural production by crop type	m Tonnes
Total annual value of agricultural production	US$

Appendix 2. RAP internal process indicators

Indicator label	Primary indicator and sub-indicator name
SERVICE and SOCIAL ORDER	
I-1	***Actual*** **water delivery service to individual ownership units (e.g. field or farm)**
I-1A	Measurement of volumes
I-1B	Flexibility
I-1C	Reliability
I-1D	Apparent equity
I-2	***Stated*** **water delivery service to individual ownership units (e.g. field or farm)**
I-2A to I-2B	Same sub-indicators as for I-1
I-3	***Actual*** **water delivery service at the most downstream point in the system operated by a paid employee**
I-3A	Number of fields downstream of this point
I-3B	Measurement of volumes
I-3C	Flexibility
I-3D	Reliability
I-3E	Apparent equity
I-4	***Stated*** **water delivery service at the most downstream point operated by a paid employee**
I-4A to I-4E	Same sub-indicators as for I-3
I-5	***Actual*** **water delivery service by the main canals to the second level canals**
I-5A	Flexibility
I-5B	Reliability
I-5C	Equity
I-5D	Control of flow rates to the submain as stated
I-6	Stated water delivery service by the main canals to the second level canals
I-6A to I-6D	Same sub-indicators as for I-5
I-7	**Social "order" in the canal system operated by paid employees**
I-7A	Degree to which deliveries are ***NOT*** taken when not allowed, or at flow rates greater than allowed
I-7B	Noticeable ***non***-existence of unauthorized turnouts from canals
I-7C	Lack of vandalism of structures
MAIN CANAL	
I-8	**Cross-regulator hardware (main canal)**
I-8A	Ease of cross-regulator operation under the current target operation
I-8B	Level of maintenance of the cross-regulators
I-8C	Lack of water level fluctuation
I-8D	Travel time of a flow rate change throughout this canal level
I-9	**Turnouts from the main canal**
I-9A	Ease of turnout operation under the current target operation
I-9B	Level of maintenance
I-9C	Flow rate capacities

Indicator label	Primary indicator and sub-indicator name
I-l0	**Regulating reservoirs in the main canal**
I-10A	Suitability of the number of location(s)
I-10B	Effectiveness of operation
I-10C	Suitability of the storage/buffer capacities
I-10D	Maintenance
I-11	**Communications for the main canal**
I-11A	Frequency of communications with the next *higher* level
I-11B	Frequency of communications by operators or supervisors with their customers
I-11C	Dependability of voice communications by phone or radio
I-11D	Frequency of visits by upper level supervisors to the field
I-11E	Existence and frequency of remote monitoring (either automatic or manual) at key ***spill points,*** including the end of the canal
I-11F	Availability of roads along the canal
I-12	**General conditions for the main canal**
I-12A	General level of maintenance of the canal floor and canal banks
I-12B	General lack of *undesired* seepage (note: If deliberate conjunctive use is practised, some seepage may be desired)
I-12C	Availability of proper equipment and staff to adequately maintain this canal
I-12D	Travel time from the maintenance yard to the most distant point along this canal (for crews and maintenance equipment)
I-13	**Operation of the main canal**
I-13A	How frequently do the headworks respond to realistic real time feedback from the operators/ observers of this canal level?
I-13B	Existence and effectiveness of water ordering/delivery procedures to match actual demands
I-13C	Clarity and correctness of instructions to operators
I-13D	How frequently is the whole length of this canal checked for problems and reported to the office?
SECOND LEVEL CANALS	
I-14 to I-19	Same indicators as for main canal
THIRD LEVEL CANALS	
I-20 to I-25	Same indicators as for main and second level canals
BUDGETS, EMPLOYEES, WUAs	
I-26	**Budgets**
I-26A	What percentage of the total project (including WUA) O&M is collected as in-kind services, and/or water fees from water users?
I-26B	Adequacy of the actual dollars and in-kind services that are available (from all sources) to sustain adequate O&M with the present mode of operation
I-26C	Adequacy of spending on modernization of the water delivery operation/structures (as contrasted to rehabilitation or regular operation)
I-27	**Employees**
I-27A	Frequency and adequacy of training of operators and middle managers (not secretaries and drivers)
I-27B	Availability of written performance rules

Indicator label	Primary indicator and sub-indicator name
I-27C	Power of employees to make decisions
I-27D	Ability of the project to dismiss employees with cause
I-27E	Rewards for exemplary service
I-27F	Relative salary of an operator compared to a day labourer
I-28	**WUAs**
I-28A	Percentage of all project users who have a functional, formal unit that participates in water distribution
I-28B	Actual ability of the strong WUAs to influence real-time water deliveries to the WUA
I-28C	Ability of the WUA to rely on effective outside help for enforcement of its rules
I-28D	Legal basis for the WUAs
I-28E	Financial strength of WUAs
I-29	**Mobility and size of operations staff, based on the ratio of operating staff to the number of turnouts**
I-30	**Computers for billing and record management: The extent to which computers are used for billing and record management**
I-31	**Computers for canal control: The extent to which computers (either central or on-site) are used for canal control**

SPECIAL INDICATORS THAT DO NOT HAVE A 0–4 RATING SCALE

I-35 Turnout density: Number of water users downstream of employee-operated turnouts

I-36 Turnouts/operator: (Number of turnouts operated by paid employees)/(paid employees)

I-37 Main canal chaos: (Actual/stated) overall service by the main canal

I-38 Second level chaos: (Actual/stated) overall service at the most downstream point operated by a paid employee

I-39 Field level chaos: (Actual/stated) overall service to the individual ownership units

Appendix 3. Example of a RAP service indicator

No.	Primary indicator	Sub-indicator	Ranking criteria	Wt
I-1	Actual water delivery service to individual ownership units (e.g. field or farm)			
I-1A		Measurement of volumes to the individual units (0–4)	4 – Excellent measurement and control devices, properly operated and recorded 3 – Reasonable measurement and control devices, average operation 2 – Useful but poor measurement of volumes and flow rates 1 – Reasonable measurement of flow rates, but not of volumes 0 – No measurement of volumes or flows	1
I-1B		Flexibility to the individual units (0–4)	4 – Unlimited frequency, rate, and duration, but arranged by users within a few days 3 – Fixed frequency, rate, or duration, but arranged 2 – Dictated rotation, but it approximately matches the crop needs 1 – Rotation deliveries, but on a somewhat uncertain schedule 0 – No established rules	2
I-1C		Reliability to the individual units (0–4)	4 – Water always arrives with the frequency, rate, and duration promised. Volume is known 3 – Very reliable in rate and duration, but occasionally there are a few days of delay. Volume is known 2 – Water arrives about when it is needed and in the correct amounts. Volume is unknown 1 – Volume is unknown, and deliveries are fairly unreliable, but less than 50% of the time 0 – Unreliable frequency, rate, duration, more than 50% of the time, and volume delivered is unknown	4
I-1D		Apparent equity to individual units (0–4)	4 – All fields throughout the project and within tertiary units receive the same type of water delivery service 3 – Areas of the project receive the same amounts of water, but within an area the service is somewhat inequitable 2 – Areas of the project receive somewhat different amounts (unintentionally), but within an area it is equitable 1 – There are medium inequities both between areas and within areas 0 – There are differences of more than 50% throughout the project on a fairly widespread basis	4

Appendix 4

		Malaysia			Indonesia		Viet Nam		**China**		Philippines			Pakistan			India
Item Description	Units	MADA	KERIAN KUMP	Penang	Lodoyo	Lakbok	Dau Tieng	Cau Son, Cam Son	**Zhanghe**	**Jiamakou**	MARIIS	SMIP Over All	Narayani	AkramWah	Fuleli-Guni	Ghotki	Krishna
Stated Efficiencies																	
Stated conveyance efficiency of imported canal water (accounts for seepage and spills and tail end flows)	%	84	61	80	60	57	50	50	**65**	**78**	60	75	70	80	80	80	70
Weighted *field* irrigation efficiency from stated efficiencies	%	70	70	89	68	78	75	77	**69**	**60**	75	68	65	70	74	66	67
Areas																	
Physical area of irrigated cropland in the command area (not including multiple cropping)	Ha	96 474	23 560	6 888	12 232	18 288	44 000	24 140	**121 567**	**16 780**	43 131	64 000	28 700	215 511	403 103	400 000	201 600
Irrigated crop area in the command area, including multiple cropping	Ha	192 948	44 405	13 776	32 232	33 317	106 300	42 706	**168 320**	**16 860**	82 172	136 040	58 163	56 056	70 163	224 478	300 000
Cropping intensity in the command area including double cropping	none	2.00	1.88	2.00	2.64	2	2.42	1.77	**1.38**	**1.00**	1.91	2.13	2.03	0.26	0.17	0.56	1.49
External sources of water for the command area																	
Surface *irrigation* water inflow from outside the *command* area (gross at diversion and entry points)	MCM	1 155	568	197	280	210	1 104	235	**500**	**58**	1 728	751	314	1 386	3 718	3 117	2 180
Gross precipitation in the irrigated fields in the command area	MCM	1 922	667	167	162	257	774	336	**821**	**67**	455	1 247	506	395	0	472	1 723
Effective precipitation to irrigated fields (not including salinity removal)	MCM	214	61	17	70	63	213	73	**536**	**39**	131	193	100	66	0	192	823
Net aquifer *withdrawl* due to irrigation in the command area	MCM	0	0	0	0	0	0	0	**0**	**0**	0	0	0	0	0	0	0
Total *external* **water** supply for the project – including gross ppt. and *net* aquifer withdrawl, but excluding internal recirculation	MCM	3 077	1 235	365	442	467	1 878	571	**1 321**	**125**	2 183	1 998	821	1 781	3 718	3 589	3 903
Total external irrigation supply for the project	MCM								**500**	**58**	1 728	751	314	1 386	3 718	3 117	2 180
"Internal" Water Sources																	
Internal *surface* water recirculation by farmer or project in command area	MCM	125	89	0	1	79	276	116	**30**	**0**	286	137	0	0	0	0	0
Gross *groundwater* pumped by farmers within command area	MCM	0	0	0	3	0	0	0	**0**	**2**	0	24	14	0	0	9	1
Groundwater pumped by Project Authorities and applied to the command area	MCM	0	0	0	0	0	0	0	**0**	**0**	0	0	0	0	0	474	0
Gross total annual volume of project authority irrigation supply.	MCM								**500**	**58**	2 014	841	314	1 386	3 718	3 591	2 180
Total groundwater pumped and dedicated to the command area	MCM								**0**	**2**	0	24	14	0	0	483	1
Groundwater pumped by Project Authorities and applied to the command area, minus net groundwater withdrawl (this is to avoid double counting. Also, all of net is applied to this term, although some might be applied to farmers)	MCM								**0**	**0**	0	0	0	0	0	474	0
Estimated total gross internal surface water + groundwater	MCM	125	89	0	5	79	276	116	**30**	**2**	286	162	14	0	0	483	1
Irrigation water delivered to users																	
Internal authority water sources are stated to have a conveyance efficiency of:	%	95	87	93	87	86	83	83	**90**	**90**	60	75	90	80	80	80	80
Delivery of *external* surface ***irrigation*** water to *users* – using stated conveyance efficiency	MCM	967	349	158	168	118	552	118	**325**	**45**	1 037	563	220	1 109	2 974	2 494	1 526
All other ***irrigation*** water to users (surface recirculation plus all well pumping, with stated conveyance efficiencies, using 100% for farmer pumping and farmer surface diversions)	MCM								**30**	**2**	172	139	14	0	0	388	1

Item Description	Units	Malaysia			Indonesia		Viet Nam		**China**		Philippines			Pakistan			India
		MADA	KERIAN KUMP	Penang	Lodoyo	Lakbok	Dau Tieng	Cau Son, Cam Son	**Zhanghe**	**Jiamakou**	MARIIS	SMIP Over All	Narayani	AkramWah	Fuleli-Guni	Ghotki	Krishna
Total *irrigation* water *deliveries to users* (external surface irrigation water + internal diversions and pumping water sources), reduced for conveyance efficiencies	MCM	1 083	426	158	172	186	782	214	**355**	**47**	1 208	702	234	1 109	2 974	2 882	1 527
Total irrigation water (internal plus external) – just for intermed. value	MCM								**530**	**60**	2 014	913	328	1 386	3 718	3 601	2 181
Overall conveyance efficiency of project authority delivered water	%								**65**	**78**	60	75	70	80	80	80	70
Net Field Irrigation requirements																	
ET of irrigated fields in the command area	MCM	481	265	94	166	183	552	226	**699**	**61**	449	550	277	684	901	2 112	918
ET of irrigation water in the command area (ET – effective precipitation)	MCM	267	204	77	95	120	339	153	**163**	**21**	318	357	177	617	901	1 921	95
Irrigation water needed for salinity control (net)	MCM	0	0	0	7	6	20	8	**0**	**0**	6	1	0	63	84	95	0
Irrigation water needed for special practices	MCM	0	0	0	8	5	44	7	**64**	**7**	49	91	27	17	35	5	450
Total NET irrigation water requirements (ET – eff ppt + salt control + special practices)	MCM	267	204	77	110	130	402	168	**227**	**28**	372	449	204	696	1 020	2 021	545
Other Key Values																	
Flow rate *capacity* of main canal(s) at diversion point(s)	cms	141	34	14	19	25	90	31	**130**	**16**	100	60	24.1	105	509	326	216
Actual peak flow rate of the main canal(s) at diversion point(s) this year	cms	141	31	13	12	24	87	31	**101**	**16**	95	60	22.1	79	408	312	135
Peak NET irrigation requirement for field, including any special requirements	cms	23	15	4	6	8	25	10	**62**	**5**	21	35	11.9	57	78	131.1	122
Peak GROSS irrigation requirement, including all inefficiencies	cms	115	51	10	17	22	99	25	**150**	**11**	113	74	19.4	113	283	233.7	488
ANNUAL or One-Time External INDICATORS for the Command Area																	
Peak liters/sec/ha of surface irrigation inflows to canal(s) this year	LPS/Ha	1.46	1.30	1.89	0.98	1	1.98	1.28	**0.83**	**0.95**	2.20	0.94	0.77	0.37	1.01	0.78	0.67
RWS *Relative water supply* for the irrigated part of the command area (Total external water supply)/(Field ET during growing seasons + water for salt control – Effective precipitation)	none	12.29	6.14	4.85	4.06	4	4.67	3.40	**5.82**	**4.39**	5.86	4.45	4.02	2.56	3.64	1.78	7.16
Annual ***Command Area Irrigation Efficiency*** [100 x (Crop ET + Leaching needs – Effective ppt)/(Surface irrigation diversions + Net groundwater)]	%	23	36	39	42	60	36	71	**45**	**49**	22	60	65	50	27	65	25
Field Irrigation Efficiency (computed) = [Crop ET-Effective ppt + LR water]/[Total Water Delivered to Users] x 100	%	25	48	49	68	68	51	78	**64**	**61**	31	64	87	63	34	70	36
RGCC – *Relative Gross Canal Capacity* – (Peak Monthly Net Irrigation Requirement)/(Main Canal Capacity)	none	0.16	0.44	0.29	0.33	0	0.28	0.32	**0.48**	**0.31**	0.21	0.59	0.49	0.54	0.15	0.40	0.56
RACF – *Relative Actual Canal Flow* – (Peak Monthly Net Irrigation Requirement)/(Peak Main Canal Flow Rate)	none	0.16	0.49	0.31	0.54	0	0.29	0.32	**0.62**	**0.31**	0.22	0.59	0.54	0.72	0.19	0.42	0.90
Gross annual tonnage of agricultural production by crop type	m Tonnes																
Total annual value of agricultural production	US$	141 957 727	19 944 537	10 917 445	24 596 251	21 378 846	28 772 000	25 382 933	**187 937 265**	**69 848 833**	56 199 902	52 680 003	21 614 250	29 928 364	27 420 485	119 967 401	199 184 839

Appendix 5: Internal Performance Indicators

Indicator Label	Indicator Name	Weighting Factor	Sum of weighting factors	MADA	KERIAN KUMP	Penang	Muda*	Kemubu*	Lampao*	Nam Oon	Lodoyo	Lakbok	MARIIS**	Dau Tieng	Cau-Son, Cam-Son	**Zhanghe**	**Jiamakou**	West Krishna Audhra Pradesh	Majalgaon*	Dantiwada*	Bhakra*	SMIP	Narayani	AkramWah	Fuleli-Guni	Ghotki	Dez*	Guilan*	Beni Amir*	Office du Niger*	Rio Yaqui*	Coello*	Saldana*	Cupatitzio*	Rio Mayo*	Sehan*
				Malaysia					Thailand		Indonesia		Philippines	Viet Nam		**China**		India				Nepal		Pakistan			Iran		Morocco		DR	Colombia		Mexico		Turkey
SERVICE and SOCIAL ORDER																																				
I-1	***Actual*** Water Delivery Service to Individual Ownership Units (e.g., field or farm)		11.0	2.3	2.1	2.3	2.5	2.4	1.0	1.06	1.8	1.5	1.8	1.6	1.3	**1.9**	**3.1**	0.8	2.0	2.4	0.9	1.1	0.5	1.5	1.5	1.2	0.9	2.2	3.0	2.5	1.6	2.4	2.4	2.4	3.0	2.8
I-1A	*Measurement of volumes*	1.0		0.0	0.0	0.3	2.0	0.0	0.0	0.65	0.0	0.0	0.0	0.0	0.0	**0.0**	**1.5**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.8	1.0	0.5	2.5	3.0
I-1B	*Flexibility*	2.0		2.0	1.7	2.5	2.0	2.0	1.5	0.8	1.7	1.0	2.0	1.0	1.0	**1.8**	**2.5**	0.5	1.0	2.0	1.0	1.0	0.0	1.5	1.5	1.5	1.0	2.0	3.0	4.0	4.0	3.0	2.5	3.0	3.5	3.0
I-1C	*Reliability*	4.0		2.0	2.0	2.0	2.5	2.5	1.0	1.2	1.8	1.7	2.0	2.0	1.0	**2.3**	**3.0**	1.0	1.0	2.5	1.0	1.5	1.0	1.5	1.5	1.5	1.0	2.0	4.0	3.0	1.5	2.0	2.0	2.0	2.5	3.0
I-1D	*Apparent equity*	4.0		3.3	2.8	3.0	3.0	3.0	1.0	1.6	2.3	2.0	2.0	2.0	2.0	**2.0**	**4.0**	1.0	4.0	3.0	1.0	1.0	0.5	2.0	2.0	1.0	1.0	3.0	2.0	2.0	1.0	3.0	3.0	3.0	3.5	2.5
I-2	***Stated*** Water Delivery Service to Individual Ownership Units (e.g., field or farm)		11.0	2.7	2.5	2.3	2.4	2.6	2.4	1.32	2.6	1.5	2.5	1.8	0.7	**2.0**	**3.5**	2.5	2.3	2.4	1.5	1.8	1.6	2.8	2.8	2.1	2.2	2.3	3.8	2.9	2.8	2.6	3.0	2.8	3.0	3.0
I-2A	*Measurement of volumes*	1.0		0.0	3.0	0.3	0.0	1.0	2.0	0.87	2.3	1.3	0.0	0.0	0.0	**0.0**	**4.0**	1.0	1.0	0.0	0.0	0.0	0.0	2.0	2.0	3.0	3.0	1.0	4.0	0.0	1.0	3.0	3.0	1.0	2.5	3.5
I-2B	*Flexibility*	2.0		3.0	2.0	2.3	2.0	2.0	2.0	0.8	2.0	1.0	4.0	2.0	0.0	**1.8**	**3.0**	1.7	2.0	2.0	1.0	2.0	1.0	2.5	2.5	2.0	2.5	2.0	3.0	4.0	3.0	3.0	3.0	3.0	3.5	3.0
I-2C	*Reliability*	4.0		2.0	2.0	2.0	2.5	3.0	2.0	2.0	2.3	1.3	2.0	2.0	0.0	**2.8**	**3.0**	2.7	1.0	2.5	1.5	2.0	2.0	3.0	3.0	2.0	2.0	2.0	4.0	2.0	2.0	2.0	3.0	2.0	2.5	3.0
I-2D	*Apparent equity*	4.0		4.0	3.0	3.0	3.0	3.0	3.0	1.6	3.3	2.0	3.0	2.0	2.0	**2.0**	**4.0**	3.0	4.0	3.0	2.0	2.0	2.0	3.0	3.0	2.0	2.0	3.0	4.0	4.0	4.0	3.0	3.0	4.0	3.5	3.0
I-3	***Actual*** Water Delivery Service at the most downstream point in the system operated by a paid employee		17.0	1.9	2.0	2.0	2.4	2.0	0.9	0.76	1.4	1.5	1.2	1.4	0.7	**1.2**	**3.1**	0.9	1.3	1.4	1.3	0.7	0.4	0.9	0.9	0.9	1.8	1.8	2.7	2.4	1.2	2.2	2.4	2.2	3.1	2.9
I-3A	*Number of fields downstream of this point*	1.0		1.3	2.0	2.5	3.0	0.0	3.0	0.69	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	4.0	1.0	3.0	2.5	4.0	4.0	4.0
I-3B	*Measurement of volumes*	4.0		0.0	1.8	0.3	1.5	1.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	**0.0**	**3.0**	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	2.5	0.0	2.5	0.0	0.0	0.8	2.0	0.5	2.5	3.0
I-3C	*Flexibility*	4.0		2.0	2.0	3.0	2.5	2.5	1.5	0.6	1.8	1.7	2.0	2.0	1.0	**1.5**	**3.0**	1.5	1.0	2.0	1.0	1.0	0.0	1.0	1.0	1.0	2.0	2.0	3.0	4.0	3.0	3.0	2.5	3.0	3.5	3.0
I-3D	*Reliability*	4.0		2.3	1.7	2.0	2.5	2.0	1.0	0.9	1.3	2.0	1.5	2.0	1.0	**2.0**	**3.0**	1.7	1.0	1.5	1.0	1.0	0.5	1.0	1.0	1.0	1.5	2.0	4.0	3.0	1.0	2.0	2.0	2.0	2.5	3.0
I-3E	*Apparent equity*	4.0		3.3	2.7	2.5	3.0	3.0	0.5	1.6	2.0	2.7	1.5	2.0	1.0	**1.8**	**4.0**	1.3	3.5	2.0	1.0	1.0	1.0	2.0	2.0	2.0	1.5	3.0	2.0	2.0	1.0	3.0	3.0	3.0	3.5	2.5
I-4	***Stated*** Water Delivery Service at the most downstream point in the system operated by a paid employee		17.0	2.4	1.8	1.7	2.1	2.0	2.8	1.69	2.5	2.2	2.4	1.4	1.4	**2.0**	**3.4**	2.1	1.9	1.6	3.1	1.5	1.2	3.1	3.1	2.2	2.5	1.8	3.8	3.1	1.7	2.8	3.0	2.6	3.1	3.1
I-4A	*Number of fields downstream of this point*	1.0		0.0	0.0	0.5	2.0	0.0	3.0	1.54	1.3	0.0	0.0	0.0	0.0	**0.0**	**0.0**	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	3.0	4.0	0.0	1.0	3.0	2.5	4.0	4.0	4.0
I-4B	*Measurement of volumes*	4.0		1.3	1.0	1.0	0.5	1.0	2.0	0.0	2.0	1.7	2.0	0.0	0.0	**1.5**	**4.0**	2.3	1.0	0.0	3.0	0.0	0.0	3.0	3.0	3.0	4.0	0.0	3.0	4.0	1.0	3.0	3.0	1.0	2.5	3.5
I-4C	*Flexibility*	4.0		2.7	2.0	2.3	2.5	2.5	2.0	2.0	2.0	2.3	3.0	2.0	2.0	**2.2**	**2.7**	1.7	2.0	2.0	2.0	2.0	2.5	3.5	3.5	2.0	2.5	2.0	4.0	2.0	2.0	3.0	3.0	3.0	3.5	3.0
I-4D	*Reliability*	4.0		2.3	2.0	2.0	2.5	2.0	4.0	2.2	3.0	2.3	2.0	2.0	2.0	**3.0**	**3.7**	2.0	1.0	1.5	4.0	2.0	2.0	3.0	3.0	2.0	2.0	2.0	4.0	4.0	2.0	2.0	3.0	2.0	2.5	3.0
I-4E	*Apparent equity*	4.0		3.7	2.7	2.0	3.0	3.0	3.0	2.7	3.3	3.0	3.0	2.0	2.0	**2.0**	**4.0**	3.0	4.0	3.0	4.0	2.0	0.5	3.5	3.5	2.5	2.0	3.0	4.0	3.0	2.0	3.0	3.0	4.0	3.5	2.5
I-5	***Actual*** Water Delivery Service by the Main Canals to the Second Level Canals		4.5	2.9	2.6	2.8	2.6	3.3	1.3	2.73	1.7	1.7	2.7	2.5	2.2	**3.1**	**3.2**	1.0	3.0	3.3	1.8	1.7	0.4	1.4	1.2	1.2	0.9	3.0	2.5	2.7	1.1	2.6	2.1	2.4	2.8	2.8
I-5A	*Flexibility*	1.0		1.0	3.0	3.0	2.5	4.0	1.5	2.11	0.5	1.3	2.0	3.0	3.0	**3.0**	**3.0**	1.0	1.0	3.2	1.0	1.0	0.0	1.0	1.0	1.0	1.5	3.0	1.0	4.0	2.0	2.0	2.0	2.0	3.0	2.0
I-5B	*Reliability*	1.0		3.7	3.3	3.5	2.0	3.0	1.0	3.1	2.0	3.0	3.0	3.0	1.0	**3.8**	**3.0**	2.0	3.0	3.5	3.0	3.0	0.0	1.5	1.5	1.5	1.0	3.0	4.0	3.0	2.0	2.5	3.0	3.0	3.0	3.0
I-5C	*Equity*	1.0		4.0	3.3	3.3	2.5	3.5	2.0	3.0	2.8	2.7	4.0	3.0	3.0	**2.8**	**4.0**	1.3	3.5	4.0	1.0	2.0	0.5	1.5	1.5	1.5	1.0	3.0	4.0	2.0	1.0	4.0	3.0	3.0	3.0	3.0
I-5D	*Control of flow rates to the submain as stated*	1.5		3.0	1.5	1.9	3.0	3.0	1.0	2.7	1.5	0.3	2.0	1.5	2.0	**3.0**	**3.0**	0.0	4.0	2.8	2.0	1.0	1.0	1.5	1.0	1.0	0.5	3.0	1.5	2.0	0.0	2.0	1.0	2.0	2.5	3.2
I-6	***Stated*** Water Delivery Service by the Main Canals to the Second Level Canals		4.5	3.3	3.0	3.0	2.6	4.0	2.9	2.86	2.5	3.0	3.6	2.3	2.2	**3.3**	**3.6**	1.7	2.9	3.0	2.6	2.0	1.6	2.9	2.9	2.9	2.4	3.3	4.0	4.0	3.0	2.9	3.1	3.6	2.8	3.3
I-6A	Flexibility	1.0		2.0	3.0	3.0	2.5	4.0	2.0	2.52	1.7	2.3	2.0	3.0	2.0	**3.3**	**3.0**	1.0	1.0	2.0	1.0	1.0	2.5	2.5	2.5	1.0	3.0	3.0	4.0	4.0	2.0	2.0	2.5	2.0	3.0	3.0
I-6B	Reliability	1.0		3.7	3.0	3.0	2.0	4.0	1.0	3.3	3.0	4.0	4.0	3.0	3.0	**3.5**	**3.0**	2.7	3.0	3.0	3.0	3.0	2.0	1.5	1.5	3.0	2.0	3.0	4.0	4.0	4.0	2.5	3.0	4.0	3.0	3.0

Indicator Label	Indicator Name	Weighting Factor	Sum of weighting factors	Malaysia					Thailand		Indonesia		Philippines	Viet Nam		**China**		India				Nepal		Pakistan			Iran		Morocco		▯DR	Colombia		Mexico		Turkey
				MADA	KERIAN KUMP	Penang	Muda*	Kemubu*	Lampao*	Nam Oon	Lodoyo	Lakbok	MARIIS**	Dau Tieng	Cau-Son, Cam-Son	**Zhanghe**	**Jiamakou**	West Krishna Audhra Pradesh	Majalgaon*	Dantiwada*	Bhakra*	SMIP	Narayani	AkramWah	Fuleli-Guni	Ghotki	Dez*	Guilan*	Benl Amir*	Office du Niger*	Rio Yaqui*	Coello*	Saldana*	Cupatitzio*	Rio Mayo*	Sehan*
I-6C	Equity	1.0	▯	4.0	3.0	3.0	2.5	4.0	4.0	2.9	3.0	2.7	4.0	2.0	2.0	**3.3**	**4.0**	1.3	3.0	4.0	3.0	2.0	0.5	3.0	3.0	3.0	3.0	3.0	4.0	4.0	3.0	4.0	4.0	4.0	3.0	3.0
I-6D	Control of flow rates to the submain as stated	1.5	▯	3.3	3.0	3.0	3.0	4.0	4.0	2.7	2.3	3.0	4.0	1.5	2.0	**3.3**	**4.0**	1.7	4.0	3.0	3.0	2.0	1.5	4.0	4.0	4.0	2.0	4.0	4.0	4.0	3.0	3.0	3.0	4.0	2.5	4.0
I-7	Social "Order" in the Canal System operated by paid employees	▯	4.0	2.7	2.9	2.1	2.0	1.5	2.3	1.49	3.2	1.8	1.0	1.3	2.5	**3.3**	**0.0**	1.8	2.8	3.0	1.5	1.0	1.5	1.4	1.4	1.3	0.5	2.5	3.0	2.3	1.8	2.5	3.0	2.3	3.0	3.0
I-7A	*Degree to which deliveries are **NOT** taken when not allowed, or at flow rates greater than allowed*	2.0	▯	2.7	3.0	2.5	2.0	2.0	2.0	1.55	3.3	2.0	1.0	2.0	3.0	**3.0**	**0.0**	2.5	3.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.0	3.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0
I-7B	*Noticeable **non**-existence of unauthorized turnouts from canals*	1.0	▯	3.0	3.0	1.5	3.0	1.0	2.0	1.0	3.0	1.7	2.0	1.0	2.0	**3.0**	**0.0**	1.0	3.0	3.0	2.0	1.0	1.0	1.5	1.5	1.0	0.0	1.0	3.0	3.0	1.0	3.0	3.0	1.0	3.0	3.0
I-7C	*Lack of vandalism of structures*	1.0	▯	2.3	2.7	1.8	1.0	1.0	3.0	3.4	3.2	1.7	0.0	0.0	2.0	**4.0**	**0.0**	1.0	2.0	3.0	2.0	1.0	3.0	2.0	2.0	2.0	0.0	3.0	3.0	2.0	2.0	1.0	3.0	2.0	3.0	3.0
MAIN CANAL																																				
I-8	Cross regulator hardware (Main Canal)	▯	7.0	1.5	1.3	2.3	3.1	3.5	1.5	2.04	1.7	1.6	2.1	0.9	0.7	**2.3**	**1.4**	0.8	3.4	3.3	2.2	1.2	1.7	1.7	1.6	1.6	1.7	3.1	3.6	2.8	1.6	3.1	3.2	2.8	1.9	2.2
I-8A	*Ease of cross regulator operation under the current target operation. This does not mean that the current targets are being met; rather this rating indicates how easy or difficult it would be to move the cross regulators to meet the targets*	1.0	▯	3.3	2.5	2.5	4.0	4.0	2.0	1.77	2.7	2.3	2.0	2.0	2.0	**2.8**	**3.0**	1.3	4.0	2.8	2.5	2.5	2.5	2.0	2.0	2.0	1.0	4.0	4.0	3.0	3.0	4.0	4.0	3.5	3.0	2.5
I-8B	*Level of maintenance of the cross regulators*	1.0	▯	4.0	2.7	2.5	3.0	2.5	2.5	2.8	2.3	1.7	2.0	2.0	3.0	**4.0**	**3.0**	1.7	3.5	3.6	3.0	2.0	2.5	2.0	1.5	1.0	3.0	3.0	3.0	2.5	2.0	3.0	3.5	2.0	3.5	3.0
I-8C	*Lack of water level fluctuation*	3.0	▯	0.3	0.0	1.8	3.0	4.0	2.0	1.6	0.0	0.7	1.0	0.0	0.0	**2.0**	**0.0**	0.7	4.0	3.0	2.0	0.0	1.0	2.0	2.0	2.0	2.0	3.0	4.0	2.0	0.0	3.0	3.0	3.0	1.0	2.0
I-8D	*Travel time of a flow rate change throughout this canal level*	2.0	▯	1.0	2.0	3.0	3.0	3.0	0.0	2.0	3.3	2.7	4.0	1.0	0.0	**1.5**	**2.0**	0.3	2.0	4.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	3.0	3.0	4.0	3.0	3.0	3.0	2.5	2.0	2.0
I-9	Turnouts from the Main Canal	▯	3.0	3.6	2.2	3.0	3.3	3.3	2.5	1.95	2.9	1.9	2.3	2.3	2.3	**2.8**	**3.7**	2.2	3.7	2.7	1.3	2.0	1.8	1.8	1.5	1.8	3.2	3.5	1.8	2.0	2.3	2.3	3.3	2.3	2.8	3.2
I-9A	*Ease of turnout operation under the current target operation. This does not mean that the current targets are being met; rather this rating indicates how easy or difficult it would be to move the turnouts and measure flows to meet the targets*	1.0	▯	3.7	2.7	2.8	3.0	3.5	2.0	2.2	3.0	2.3	3.0	2.0	2.0	**3.0**	**4.0**	2.7	4.0	3.0	1.0	2.0	1.5	2.0	2.0	2.0	2.5	4.0	2.5	2.5	1.0	2.0	2.0	2.0	2.5	3.5
I-9B	*Level of maintenance*	1.0	▯	3.0	2.2	2.8	3.0	2.5	1.5	2.8	2.7	0.7	1.0	2.0	3.0	**3.3**	**4.0**	2.0	3.0	3.0	3.0	2.0	2.0	1.5	1.5	1.5	3.0	2.5	1.0	2.5	2.0	3.0	4.0	1.0	2.0	3.0
I-9C	*Flow rate capacities*	1.0	▯	4.0	1.8	3.5	4.0	4.0	4.0	2.8	3.0	2.7	3.0	3.0	2.0	**2.0**	**3.0**	2.0	4.0	2.0	0.0	2.0	2.0	2.0	1.0	2.0	4.0	4.0	2.0	1.0	4.0	2.0	4.0	4.0	4.0	3.0
I-l0	Regulating Reservoirs in the Main Canal	▯	6.0	0.8	0.0	0.0	0.0	0.0	0.7	0.0	1.2	0.1	0.0	0.0	0.0	**3.3**	**0.0**	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I-10A	Suitability of the number of location(s)	2.0	▯	0.7	0.0	0.0	0.0	0.0	2.0	0.0	1.3	0.0	0.0	0.0	0.0	**4.0**	**0.0**	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I-10B	Effectiveness of operation	2.0	▯	0.7	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	**4.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I-10C	Suitability of the storage/buffer capacities	1.0	▯	0.7	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.7	0.0	0.0	0.0	**2.0**	**0.0**	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I-10D	Maintenance	1.0	▯	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	**2.0**	**0.0**	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I-11	Communications for the Main Canal	▯	11.0	3.2	2.0	2.3	3.3	3.0	2.6	2.79	1.3	1.2	3.8	2.1	2.3	**2.7**	**3.3**	2.2	3.6	2.9	2.1	1.3	1.7	2.1	2.1	2.1	1.5	2.5	2.0	1.4	1.5	2.7	3.6	2.0	2.9	2.9
I-11A	*Frequency of communications with the next **higher** level? (hr)*	2.0	▯	3.3	1.3	1.0	3.0	3.0	2.0	2.56	0.7	0.7	4.0	1.0	1.0	**2.5**	**4.0**	3.0	4.0	2.0	2.0	1.0	1.0	3.0	3.0	3.0	1.0	2.0	1.0	1.0	0.5	2.0	4.0	4.0	1.0	2.0
I-11B	*Frequency of communications by operators or supervisors with their customers*	2.0	▯	3.0	2.3	2.0	2.0	3.0	1.0	3.0	0.7	1.3	4.0	3.0	2.0	**3.0**	**4.0**	3.7	3.0	3.0	2.0	2.0	2.0	4.0	4.0	4.0	1.0	2.0	3.0	1.0	1.5	3.0	4.0	2.0	4.0	3.0
I-11C	*Dependability of voice communications by phone or radio*	3.0	▯	4.0	2.0	3.4	4.0	3.0	4.0	3.6	0.3	0.3	4.0	2.0	3.0	**4.0**	**4.0**	1.3	4.0	2.7	2.5	0.0	2.0	1.0	1.0	1.0	1.0	3.0	1.0	0.0	1.0	4.0	4.0	1.0	4.0	3.5
I-11D	*Frequency of visits by upper level supervisors to the field*	1.0	▯	1.7	4.0	1.8	2.0	2.0	4.0	3.4	2.7	2.0	2.0	3.0	3.0	**3.0**	**4.0**	3.0	4.0	4.0	2.0	2.0	2.0	3.0	3.0	3.0	2.0	4.0	3.0	3.0	3.0	2.0	4.0	1.0	4.0	2.0
I-11E	*Existence and frequency of remote monitoring (either automatic or manual) at key **spill** points, including the end of the canal*	1.0	▯	1.7	0.0	1.3	4.0	3.0	1.0	2.6	0.3	1.0	4.0	2.0	3.0	**0.0**	**0.0**	1.5	2.0	3.5	0.0	0.0	1.0	0.0	0.0	0.0	0.0	2.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	1.5
I-11F	*Availability of roads along the canal*	2.0	▯	3.3	2.3	3.3	4.0	3.5	3.0	1.6	3.7	2.7	4.0	2.0	2.0	**2.0**	**2.0**	1.3	4.0	3.0	3.0	3.0	2.0	1.5	1.5	1.5	3.5	2.5	3.0	4.0	3.0	3.0	4.0	3.0	3.0	4.0
I-12	General Conditions for the Main Canal	▯	5.0	3.0	3.2	3.2	3.2	2.3	2.4	2.88	2.3	1.3	3.4	1.8	3.4	**2.4**	**3.2**	1.7	2.4	2.5	2.5	1.6	1.0	1.3	1.5	1.6	3.2	2.4	3.0	3.1	2.3	3.0	2.4	2.2	3.1	2.5
I-12A	*General level of maintenance of the canal floor and canal banks*	1.0	▯	2.7	3.2	3.3	3.0	2.5	2.0	2.6	2.3	0.0	3.0	2.0	3.0	**1.8**	**3.0**	3.0	3.0	3.5	3.0	2.0	1.0	1.5	1.0	2.0	3.0	3.0	3.0	2.5	2.5	3.0	3.0	1.0	3.5	3.0

Indicator Label	Indicator Name	Weighting Factor	Sum of weighting factors	Malaysia					Thailand		Indonesia		Phi-lip-pines	Viet Nam		China		India				Nepal		Pakistan			Iran		Mo-roc-co		□DR	Colombia		Mexico		Tur-key
				MADA	KERIAN KUMP	Penang	Muda*	Kemubu*	Lampao*	Nam Oon	Lodoyo	Lakbok	MARIIS**	Dau Tieng	Cau-Son, Cam-Son	**Zhanghe**	**Jiamakou**	West Krishna Audhra Pradesh	Majalgaon*	Dantiwada*	Bhakra*	SMIP	Narayani	AkramWah	Fuleli-Guni	Ghotki	Dez*	Guilan*	Beni Amir*	Office du Niger*	Rio Yaqui*	Coello*	Saldana*	Cupatitzio*	Rio Mayo*	Sehan*
I-12B	*General lack of undesired seepage (note: if deliberate conjunctive use is practiced, some seepage may be desired)*	1.0	□	4.0	3.7	3.0	3.0	2.0	3.0	2.5	2.7	2.7	4.0	2.0	4.0	**1.5**	**2.5**	1.3	3.0	2.0	2.0	2.0	2.0	2.0	2.5	3.0	3.0	3.0	4.0	4.0	4.0	2.0	1.0	4.0	2.0	2.5
I-12C	*Availability of proper equipment and staff to adequately maintain this canal*	2.0	□	3.3	2.8	3.3	3.5	2.0	2.0	3.3	1.7	1.0	3.0	1.5	4.0	**2.5**	**3.5**	0.7	3.0	2.5	3.0	1.0	1.0	1.5	1.5	1.0	4.0	2.0	2.5	3.0	1.0	3.0	2.0	2.0	3.5	2.5
I-12D	*Travel time from the maintenance yard to the most distant point along this canal (for crews and maintenance equipment)*	1.0	□	1.7	3.3	3.3	3.0	3.0	3.0	3.1	3.0	1.7	4.0	2.0	2.0	**3.5**	**3.5**	2.7	0.0	2.0	1.5	2.0	0.0	0.0	1.0	1.0	2.0	2.0	3.0	3.0	3.0	4.0	4.0	2.0	3.0	2.0
I-13	Operation of the Main Canal	□	5.0	3.3	2.7	3.0	3.3	2.8	0.8	3.11	1.6	1.9	2.7	4.0	4.0	**3.4**	**3.2**	1.5	3.3	3.1	0.8	2.4	0.5	1.6	1.6	1.6	2.3	2.7	2.4	0.5	0.1	1.1	1.6	1.9	2.3	2.1
I-13A	*How frequently does the headworks respond to realistic real time feedback from the operators/observers of this canal level? This question deals with a mismatch of orders, and problems associated with wedge storage variations and wave travel times*	2.0	□	4.0	2.7	2.8	3.5	2.7	0.0	3.63	1.8	2.2	2.7	4.0	4.0	**3.5**	**3.0**	1.3	3.5	3.0	0.0	2.7	0.0	2.7	2.7	2.7	2.7	1.3	2.7	0.0	0.0	0.0	0.0	1.3	1.3	2.0
I-13B	*Existence and effectiveness of water ordering/delivery procedures to match actual demands. This is different than the previous question, because the previous question dealt with problems that occur AFTER a change has been made*	1.0	□	3.1	2.7	2.8	4.0	2.0	0.0	2.66	1.3	0.0	1.3	4.0	4.0	**2.9**	**3.0**	2.0	1.3	2.0	0.0	1.3	0.0	0.0	0.0	0.0	0.7	2.7	1.3	0.0	0.0	1.3	0.0	1.3	2.0	2.0
I-13C	*Clarity and correctness of instructions to operators*	1.0	□	4.0	1.3	2.9	3.0	2.7	0.0	2.14	1.9	3.1	4.0	4.0	4.0	**3.4**	**3.0**	1.5	4.0	3.5	1.3	2.7	1.3	0.0	0.0	0.0	1.3	4.0	4.0	1.3	0.0	0.0	4.0	2.7	2.7	1.3
I-13D	*How frequently is the whole length of this canal checked for problems and reported to the office? This means one or more persons physically drive all the sections of the canal*	1.0	□	1.3	4.0	4.0	2.7	4.0	4.0	4.0	1.3	1.8	2.7	4.0	4.0	**4.0**	**4.0**	1.3	4.0	4.0	2.7	2.7	1.3	2.7	2.7	2.7	4.0	4.0	1.3	1.3	0.7	4.0	4.0	2.7	4.0	3.0□
□Second Level Canals																																				
I-14	Cross regulator hardware (Second Level Canals)	□	7.0	1.7	2.1	2.2	2.1	3.9	1.8	2.04	1.3	1.6	1.7	1.1	1.9	**1.5**	**3.4**	1.0	3.4	3.2	0.6	1.5	1.6	1.5	1.3	1.1	2.3	3.1	2.6	1.9	1.1	2.1	2.7	1.9	1.8	2.8
I-14A	*Ease of cross regulator operation under the current target operation. This does not mean that the current targets are being met; rather this rating indicates how easy or difficult it would be to move the cross regulators to meet the targets*	1.0	□	3.7	3.0	3.0	2.0	4.0	1.0	2.14	3.0	2.7	2.0	2.0	2.0	**2.5**	**4.0**	2.7	4.0	4.0	0.0	1.5	2.0	1.5	1.5	0.5	2.0	4.0	4.0	3.0	0.0	3.0	3.0	3.0	2.5	2.5
I-14B	*Level of maintenance of the cross regulators*	1.0	□	2.0	2.3	3.0	3.0	3.0	1.5	3.0	3.0	1.7	1.0	2.0	3.0	**3.0**	**4.0**	1.3	3.0	3.5	0.0	1.0	1.0	1.0	1.5	1.0	3.0	3.0	3.0	2.0	0.0	3.0	2.0	2.5	2.0	3.0
I-14C	*Lack of water level fluctuation*	3.0	□	0.7	0.7	1.0	2.0	4.0	2.0	1.4	0.0	0.0	1.0	0.0	0.0	**1.0**	**2.5**	0.0	3.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	3.0	1.0	0.0	0.0	1.0	2.0	0.0	0.0	2.0
I-14D	*Travel time of a flow rate change throughout this canal level*	2.0	□	2.0	3.7	3.3	2.0	4.0	2.0	1.6	1.7	3.3	3.0	2.0	4.0	**1.0**	**4.0**	1.3	4.0	3.0	2.0	4.0	4.0	4.0	3.0	3.0	2.5	3.0	4.0	4.0	4.0	3.0	4.0	4.0	4.0	4.0
I-15	Turnouts from the Second Level Canals	□	3.0	3.4	2.6	3.0	2.5	2.0	0.8	2.27	2.5	2.1	2.0	1.8	2.0	**2.7**	**3.7**	2.4	2.5	2.5	1.5	1.7	1.0	1.8	1.8	1.5	2.3	2.2	2.2	2.3	3.0	0.8	2.7	2.3	1.8	2.3
I-15A	*Ease of turnout operation under the current target operation. This does not mean that the current targets are being met; rather this rating indicates how easy or difficult it would be to move the turnouts and measure flows to meet the targets*	1.0	□	3.7	2.7	3.0	2.5	2.0	1.0	2.2	3.0	2.3	2.0	2.0	2.0	**2.8**	**4.0**	2.7	2.5	2.0	1.5	2.0	1.0	2.0	2.0	1.5	2.0	2.5	2.5	3.0	2.0	1.5	2.0	2.0	1.5	2.0
I-15B	*Level of maintenance*	1.0	□	2.7	2.2	2.6	3.0	1.0	1.5	2.4	2.2	2.0	2.0	1.5	2.0	**3.0**	**4.0**	2.0	3.0	3.5	3.0	1.0	0.0	1.5	1.5	1.0	2.0	2.0	2.0	2.0	3.0	1.0	2.0	1.0	1.8	3.0
I-15C	*Flow rate capacities*	1.0	□	4.0	3.0	3.3	2.0	3.0	0.0	2.2	2.3	2.0	2.0	2.0	2.0	**2.3**	**3.0**	2.7	2.0	2.0	0.0	2.0	2.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0	4.0	0.0	4.0	4.0	2.0	2.0
I-16	Regulating Reservoirs in the Second Level Canals	□	6.0	0.0	0.0	0.0	□	□	□	0.0	0.0	0.0	2.5	0.0	0.0	**0.0**	**0.0**	0.0	□	□	□	0.0	0.0	0.0	0.0	0.0	□	□	□	□	□	□	□	□	□	□
I-16A	*Suitability of the number of location(s)*	2.0	□	0.0	0.0	0.0	□	□	□	0.5	0.0	0.0	2.5	0.0	0.0	**0.0**	**0.0**	0.0	□	□	□	0.0	0.0	0.0	0.0	0.0	□	□	□	□	□	□	□	□	□	□
I-16B	*Effectiveness of operation*	2.0	□	0.0	0.0	0.0	□	□	□	0.4	0.0	0.0	2.5	0.0	0.0	**0.0**	**0.0**	0.0	□	□	□	0.0	0.0	0.0	0.0	0.0□										
I-16C	*Suitability of the storage/buffer capacities*	1.0	□	0.0	0.0	0.0	□	□	□	0.6	0.0	0.0	2.5	0.0	0.0	**0.0**	**0.0**	0.0	□	□	□	0.0	0.0	0.0	0.0	0.0										
I-16D	*Maintenance*	1.0	□	0.0	0.0	0.0	□	□	□	0.4	0.0	0.0	2.5	0.0	0.0	**0.0**	**0.0**	0.0	□	□	□	0.0	0.0	0.0	0.0	0.0										
I-17	Communications for the Second Level Canals	□	11.0	2.7	1.8	2.3	2.7	2.0	2.3	2.74	1.4	1.3	2.6	2.0	2.6	**2.8**	**3.3**	1.9	2.4	2.1	0.5	1.1	1.4	1.5	1.7	1.7	1.5	2.8	1.4	1.1	2.1	2.7	2.7	1.4	3.1	2.8
I-17A	*Frequency of communications with the next **higher** level? (hr)*	2.0	□	3.3	1.3	1.0	3.0	2.0	2.0	2.62	1.0	1.0	1.0	2.0	2.0	**2.5**	**4.0**	2.0	2.0	2.0	0.0	1.0	1.0	2.0	3.0	3.0	1.0	3.0	1.0	1.0	2.0	2.0	2.0	1.0	4.0	2.0

Indicator Label	Indicator Name	Weighting Factor	Sum of weighting factors	Malaysia					Thailand		Indonesia		Phi-lip-pines	Viet Nam		**China**		India				Nepal		Pakistan			Iran		Mo-roc-co		□DR	Colombia		Mexico		Tur-key
				MADA	KERIAN KUMP	Penang	Muda*	Kemubu*	Lampao*	Nam Oon	Lodoyo	Lakbok	MARIIS**	Dau Tieng	Cau-Son, Cam-Son	**Zhanghe**	**Jiamakou**	West Krishna Audhra Pradesh	Majalgaon*	Dantiwada*	Bhakra*	SMIP	Narayani	AkramWah	Fuleli-Guni	Ghotki	Dez*	Guilan*	Benl Amir*	Office du Niger*	Rio Yaqui*	Coello*	Saldana*	Cupatitzio*	Rio Mayo*	Sehan*
I-17B	*Frequency of communications by operators or supervisors with their customers*	2.0	□	4.0	2.7	2.3	3.0	2.0	2.0	2.6	1.7	1.3	1.0	3.0	3.0	**4.0**	**4.0**	2.7	2.0	4.0	0.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	1.0	2.0	3.0	3.0	3.0	2.0	3.0	3.0
I-17C	*Dependability of voice communications by phone or radio*	3.0	□	1.7	1.0	3.3	2,5	2.0	4.0	3.6	1.0	0.7	4.0	1.0	3.0	**4.0**	**4.0**	1.3	3.0	1.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	3.0	1.0	0.0	2.0	4.0	3.5	1.0	4.0	3.5
I-17D	*Frequency of visits by upper level supervisors to the field*	1.0	□	3.0	3.7	2.5	2.0	2.0	1.0	3.4	1.7	2.0	3.0	4.0	4.0	**4.0**	**4.0**	2.7	4.0	2.0	0.0	2.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	1.0	3.0	2.0	4.0	0.0	4.0	4.0
I-17E	*Existence and frequency of remote monitoring (either automatic or manual) at key* ***spill*** *points, including the end of the canal*	1.0	□	0.0	0.3	0.0	2.0	0.0	0.0	2.4	0.2	1.7	2.0	2.0	2.0	**0.0**	**0.0**	1.3	0.0	2.5	0.0	0.0	0.0	1.0	0.0	1.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I-17F	*Availability of roads along the canal*	2.0	□	3.3	2.3	3.0	3.0	3.0	2.0	1.8	2.5	2.0	4.0	1.5	2.0	**1.0**	**2.0**	2.0	2.5	2.0	2.5	2.0	2.0	1.0	1.5	1.0	3.0	3.0	3.0	2.5	2.0	3.0	2.5	3.0	2.0	3.0
I-18	General Conditions for the Second Level Canals	□	5.0	3.4	3.2	3.1	2.8	2.2	2.2	2.98	2.1	1.7	2.6	1.4	2.2	**2.6**	**3.2**	1.8	2.0	2.2	2.1	1.6	1.0	1.6	1.4	1.6	2.6	2.4	2.0	2.9	2.4	3.1	2.3	2.0	2.5	2.8
I-18A	*General level of maintenance of the canal floor and canal banks*	1.0	□	3.3	3.2	2.9	3.0	2.0	2.0	2.82	2.0	1.0	2.0	1.5	2.0	**2.0**	**3.0**	3.0	3.0	3.0	2.5	2.0	1.0	1.0	1.0	1.0	3.0	3.0	1.0	2.0	1.0	3.0	2.0	1.0	2.0	2.5
I-18B	*General lack of undesired seepage (note: if deliberate conjunctive use is practiced, some seepage may be desired)*	1.0	□	3.7	4.0	3.3	3.0	2.0	3.0	3.1	2.7	2.3	4.0	1.5	2.0	**2.3**	**2.5**	2.0	3.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0	2.0	3.0	4.0	4.0	4.0	3.0	1.5	4.0	2.0	2.5
I-18C	*Availability of proper equipment and staff to adequately maintain this canal*	2.0	□	3.5	2.7	3.0	2.5	2.0	1.5	3.4	2.3	1.0	3.0	1.0	2.0	**2.3**	**4.0**	1.0	2.0	2.5	2.0	1.0	0.0	1.0	1.0	1.0	3.0	2.0	1.0	3.0	2.0	3.0	2.0	1.0	2.5	3.0
I-18D	*Travel time from the maintenance yard to the most distant point along this canal (for crews and maintenance equipment)*	1.0	□	3.0	3.7	3.5	3.0	3.0	3.0	2.6	1.3	3.0	1.0	2.0	3.0	**4.0**	**2.5**	2.0	0.0	1.0	2.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	3.0	2.5	3.0	3.5	4.0	3.0	3.5	3.0
I-19	Operation of the Second Level Canals	□	5.0	3.4	2.7	2.9	3.1	3.0	1.5	2.66	1.8	1.7	3.1	2.4	2.7	**3.1**	**3.6**	1.3	3.1	3.1	1.3	2.1	0.3	1.3	1.1	1.3	2.3	4.0	2.4	2.7	2.1	2.9	3.5	1.7	2.9	3.3
I-19A	*How frequently does the headworks respond to realistic real time feedback from the operators/observers of this canal level? This question deals with a mismatch of orders, and problems associated with wedge storage variations and wave travel times*	2.0	□	2.7	2.5	2.8	2.7	2.7	0.7	2.72	1.3	1.3	4.0	2.7	2.7	**3.0**	**3.5**	0.0	4.0	2.7	1.3	2.7	0.0	2.7	1.3	1.3	2.7	4.0	1.3	4.0	2.7	2.0	4.0	1.3	3.3	2.7
I-19B	*Existence and effectiveness of water ordering/delivery procedures to match actual demands. This is different than the previous question, because the previous question dealt with problems that occur AFTER a change has been made*	1.0	□	4.0	2.0	2.5	2.7	2.7	0.7	2.7	1.5	1.8	2.7	2.7	2.7	**2.9**	**3.5**	1.3	1.3	2.7	0.0	1.3	0.0	0.0	0.0	0.0	0.7	4.0	1.3	2.0	1.3	4.0	2.7	1.3	2.0	4.0
I-19C	*Clarity and correctness of instructions to operators*	1.0	□	3.6	3.6	2.8	3.3	2.7	1.3	2.26	4.0	2.7	2.0	1.3	2.7	**2.9**	**3.5**	4.0	2.0	3.3	1.3	2.7	0.0	0.0	0.0	0.0	1.3	4.0	4.0	0.0	1.3	2.7	2.7	0.7	2.0	3.3
I-19D	*How frequently is the whole length of this canal checked for problems and reported to the office? This means one or more persons physically drive all the sections of the canal*	1.0	□	4.0	3.1	3.7	4.0	4.0	4.0	2.96	1.1	1.3	2.7	2.7	2.7	**4.0**	**4.0**	1.3	4.0	4.0	2.7	1.3	1.3	1.3	2.7	4.0	4.0	4.0	4.0	3.3	2.7	4.0	4.0	4.0	4.0	4.0
□Third Level Canals□																																				
I-20	Cross regulator hardware (Third Level Canals)	□	7.0	2.0	2.0	2.5	□	□	□	2.13	2.1	0.8	□	1.7	2.3	**0.7**	**1.1**	1.3	□	□	□	1.7	2.0	1.1	1.6	1.1										
I-20A	*Ease of cross regulator operation under the current target operation. This does not mean that the current targets are being met; rather this rating indicates how easy or difficult it would be to move the cross regulators to meet the targets*	1.0	□	3.7	2.0	3.3	□	□	□	2.1	4.0	2.0	□	3.0	3.0	**0.0**	**0.0**	2.3	□	□	□	1.0	0.0	0.0	2.0	0.0										
I-20B	*Level of maintenance of the cross regulators*	1.0	□	3.0	1.3	2.5	□	□	□	3.0	2.7	1.0	□	1.0	2.0	**0.0**	**0.0**	1.3	□	□	□	0.0	0.0	0.0	1.5	0.0□										
I-20C	*Lack of water level fluctuation*	3.0	□	0.7	1.7	1.8	□	□	□	1.6	0.3	0.0	□	0.0	1.0	**2.0**	**0.0**	0.0	□	□	□	1.0	2.0	0.0	0.0	0.0										
I-20D	*Travel time of a flow rate change throughout this canal level*	2.0	□	2.7	2.7	3.3	□	□	□	1.8	3.7	1.3	□	4.0	4.0	**2.5**	**4.0**	2.7	□	□	□	4.0	4.0	4.0	4.0	4.0										
I-21	Turnouts from the Third Level Canals	□	3.0	1.3	2.2	2.8	□	□	□	2.42	2.3	1.2	□	1.7	2.0	**0.0**	**0.0**	2.2	□	□	□	0.7	0.7	2.7	2.7	2.7□										
I-21A	*Ease of turnout operation under the current target operation. This does not mean that the current targets are being met; rather this rating indicates how easy or difficult it would be to move the turnouts and measure flows to meet the targets*	1.0	□	0.0	2.3	2.8	□	□	□	2.17	3.0	1.7	□	2.0	2.0	**0.0**	**0.0**	2.7	□	□	□	1.0	0.0	3.0	3.0	3.0										

Indicator Label	Indicator Name	Weighting Factor	Sum of weighting factors	Malaysia					Thailand		Indonesia		Phi-lip-pines	Viet Nam		**China**		India				Nepal		Pakistan			Iran		Mo-roc-co		DR	Colombia		Mexico		Tur-key
				MADA	KERIAN KUMP	Penang	Muda*	Kemubu*	Lampao*	Nam Oon	Lodoyo	Lakbok	MARIIS**	Dau Tieng	Cau-Son, Cam-Son	**Zhanghe**	**Jiamakou**	West Krishna Audhra Pradesh	Majalgaon*	Dantiwada*	Bhakra*	SMIP	Narayani	AkramWah	Fuleli-Guni	Ghotki	Dez*	Guilan*	Benl Amir*	Office du Niger*	Rio Yaqui*	Coello*	Saldana*	Cupatitzio*	Rio Mayo*	Sehan*
I-21B	*Level of maintenance*	1.0		1.3	1.5	2.6				2.4	2.0	0.7		1.0	2.0	**0.0**	**0.0**	2.0				0.0	1.0	2.0	2.0	2.0										
I-21C	*Flow rate capacities*	1.0		2.7	2.7	3.0				2.7	2.0	1.3		2.0	2.0	**0.0**	**0.0**	2.0				1.0	1.0	3.0	3.0	3.0										
I-22	Regulating Reservoirs in the Third Level Canals		6.0	0.0	0.0	0.0				0.0	0.0	0.0		0.0	0.0	**1.0**	**0.0**	0.0				0.0	0.0	0.0	0.0	0.0										
I-22A	*Suitability of the number of location(s)*	2.0		0.0	0.0	0.0				0.0	0.0	0.0		0.0	0.0	**1.0**	**0.0**	0.0				0.0	0.0	0.0	0.0	0.0										
I-22B	*Effectiveness of operation*	2.0		0.0	0.0	0.0				0.0	0.0	0.0		0.0	0.0	**1.0**	**0.0**	0.0				0.0	0.0	0.0	0.0	0.0										
I-22C	*Suitability of the storage/buffer capacities*	1.0		0.0	0.0	0.0				0.0	0.0	0.0		0.0	0.0	**1.0**	**0.0**	0.0				0.0	0.0	0.0	0.0	0.0										
I-22D	*Maintenance*	1.0		0.0	0.0	0.0				0.0	0.0	0.0		0.0	0.0	**1.0**	**0.0**	0.0				0.0	0.0	0.0	0.0	0.0										
I-23	Communications for the Third Level Canals		11.0	3.1	1.4	2.3				2.45	0.6	0.5		1.5	2.3	**2.7**	**3.2**	1.3				0.9	0.6	1.6	1.6	1.9										
I-23A	*Frequency of communications with the next **higher** level? (hr)*	2.0		3.3	2.0	1.0				2.51	1.0	0.7		2.0	4.0	**3.0**	**4.0**	1.7				1.0	1.0	3.0	3.0	3.0										
I-23B	*Frequency of communications by operators or supervisors with their customers*	2.0		4.0	1.7	2.5				2.6	0.7	0.7		2.0	4.0	**4.0**	**4.0**	1.7				2.0	2.0	2.0	2.0	2.0										
I-23C	*Dependability of voice communications by phone or radio*	3.0		2.7	0.7	3.5				3.4	0.3	0.3		1.0	1.0	**4.0**	**4.0**	1.0				0.0	0.0	1.0	1.0	1.0										
I-23D	*Frequency of visits by upper level supervisors to the field*	1.0		3.0	3.0	2.5				3.4	1.3	0.7		3.0	4.0	**4.0**	**4.0**	2.7				4.0	1.0	3.0	3.0	3.0										
I-23E	*Existence and frequency of remote monitoring (either automatic or manual) at key **spill** points, including the end of the canal*	1.0		1.3	0.0	0.0				1.8	0.3	0.0		1.0	0.0	**0.0**	**0.0**	0.7				0.0	0.0	0.0	0.0	2.5										
I-23F	*Availability of roads along the canal*	2.0		3.3	1.3	2.5				1.0	0.3	0.3		0.5	1.0	**0.0**	**1.5**	0.3				0.0	0.0	1.0	1.0	1.0										
I-24	General Conditions for the Third Level Canals		5.0	3.2	2.4	3.3				2.79	2.2	2 574.8		1.6	2.2	**1.6**	**2.8**	1.8				1.4	1.0	1.0	1.4	1.2										
I-24A	*General level of maintenance of the canal floor and canal banks*	1.0		2.7	2.7	3.1				2.56	2.0	1.7		2.0	2.0	**2.3**	**2.0**	3.0				2.0	1.0	1.0	1.0	1.0										
I-24B	*General lack of undesired seepage (note: if deliberate conjunctive use is practiced, some seepage may be desired)*	1.0		3.3	2.0	4.0				3.0	2.0	3.0		2.0	2.0	**1.8**	**3.0**	3.0				1.0	1.0	2.0	2.0	3.0										
I-24C	*Availability of proper equipment and staff to adequately maintain this canal*	2.0		3.3	2.0	2.9				3.0	2.0	1.0		1.0	2.0	**0.0**	**3.0**	1.0				1.0	1.0	0.0	1.0	0.0										
I-24D	*Travel time from the maintenance yard to the most distant point along this canal (for crews and maintenance equipment)*	1.0		3.3	3.3	3.5				2.6	3.0	2.7		2.0	3.0	**4.0**	**3.0**	1.0				2.0	1.0	2.0	2.0	2.0										
I-25	Operation of the Third Level Canals		5.0	1.9	2.2	2.8				2.59	1.6	1.5		1.1	2.0	**3.5**	**3.3**	0.5				1.8	0.0	1.6	0.5	1.9										
I-25A	*How frequently does the headworks respond to realistic real time feedback from the operators/observers of this canal level? This question deals with a mismatch of orders, and problems associated with wedge storage variations and wave travel times*	2.0		1.8	1.2	2.7				2.86	1.3	1.8		0.0	3.0	**3.4**	**3.0**	0.0				2.7	0.0	2.7	0.0	2.7										
I-25B	*Existence and effectiveness of water ordering/delivery procedures to match actual demands. This is different than the previous question, because the previous question dealt with problems that occur AFTER a change has been made*	1.0		0.0	2.2	2.4				2.08	1.3	0.9		1.3	2.0	**3.4**	**3.5**	0.0				1.0	0.0	1.3	0.0	1.3										
I-25C	*Clarity and correctness of instructions to operators*	1.0		3.1	3.6	3.1				2.46	3.6	2.2		1.3	1.0	**3.4**	**3.0**	1.3				1.3	0.0	0.0	0.0	0.0										
I-25D	*How frequently is the whole length of this canal checked for problems and reported to the office? This means one or more persons physically drive all the sections of the canal*	1.0		2.7	2.7	2.9				2.96	0.4	0.9		2.7	1.0	**4.0**	**4.0**	1.0				1.3	0.0	1.3	2.7	2.7										

				Malaysia					Thailand		Indonesia		Phi-lip-pines	Viet Nam		**China**		India				Nepal		Pakistan			Iran		Mo-roc-co		□DR	Colombia		Mexico		Tur-key
Indicator Label	Indicator Name	Weighting Factor	Sum of weighting factors	MADA	KERIAN KUMP	Penang	Muda*	Kemubu*	Lampao*	Nam Oon	Lodoyo	Lakbok	MARIIS**	Dau Tieng	Cau-Son, Cam-Son	**Zhanghe**	**Jiamakou**	West Krishna Audhra Pradesh	Majalgaon*	Dantiwada*	Bhakra*	SMIP	Narayani	AkramWah	Fuleli-Guni	Ghotki	Dez*	Guilan*	Benl Amir*	Office du Niger*	Rio Yaqui*	Coello*	Saldana*	Cupatitzio*	Rio Mayo*	Sehan*
□Budgets, Employees, WUAs																																				
I-26	Budgets	□	5.0	1.3	1.9	1.3	0.4	0.8	0.9	1.52	0.9	0.3	2.6	0.4	3.6	**1.8**	**3.2**	0.0	1.6	2.0	1.0	0.0	0.0	0.8	0.4	0.8	3.0	3.4	2.0	2.2	2.0	3.2	3.0	1.0	3.0	3.4
I-26A	*What percentage of the total project (including WUA) Operation and Maintenance (O&M) is collected as in-kind services, and/or water fees from water users?*	2.0	□	0.0	0.0	0.0	0.0	0.0	0.2	0.96	0.0	0.7	4.0	0.0	4.0	**3.0**	**4.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0	1.0	0.5	3.0	4.0	4.0	1.0	4.0	4.0
I-26B	*Adequacy of the actual dollars and in-kind services that is available (from all sources) to sustain adequate Operation and Maintenance (O&M) with the present mode of operation*	2.0	□	2.0	2.7	1.3	0.0	2.0	2.0	0.8	2.0	0.0	1.0	1.0	3.0	**1.0**	**3.0**	0.0	2.0	3.0	2.5	0.0	0.0	2.0	1.0	2.0	3.5	3.0	3.0	3.0	2.0	4.0	3.0	1.0	3.0	4.0
I-26C	*Adequacy of spending on modernization of the water delivery operation/structures (as contrasted to rehabilitation or regular operation)*	1.0	□	2.7	4.0	4.0	2.0	0.0	0.1	2.8	0.3	0.0	3.0	0.0	4.0	**1.0**	**2.0**	0.0	4.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	2.0	4.0	0.0	0.0	1.0	1.0	1.0	1.0
I-27	Employees	□	9.5	2.5	2.2	2.0	1.9	1.2	1.5	0.79	2.8	2.0	2.2	2.4	2.5	**2.1**	**2.3**	1.6	1.2	2.6	1.3	1.7	1.7	□	1.3	1.2	2.3	1.9	2.6	1.6	2.0	2.4	2.3	1.6	3.5	2.3
I-27A	*Frequency and adequacy of training of operators and middle managers (not secretaries and drivers). This should include employees at all levels of the distribution system, not only those who work in the office*	1.0	□	3.7	2.3	2.9	3.0	2.0	2.0	1.37	2.3	2.0	2.0	2.0	3.0	**2.5**	**4.0**	2.0	2.0	4.0	1.0	2.0	1.0	1.0	2.0	2.0	2.0	3.0	2.5	1.0	1.0	2.0	1.0	2.0	3.0	3.0
I-27B	*Availability of written performance rules*	1.0	□	3.7	3.5	3.5	1.0	0.0	1.0	1.8	3.3	1.7	2.0	3.0	3.0	**3.8**	**3.5**	1.0	1.0	2.0	1.0	2.0	3.0	2.5	2.5	1.0	2.5	3.0	3.0	0.0	0.0	1.0	1.0	1.0	0.0	3.0
I-27C	*Power of employees to make decisions*	2.5	□	1.3	2.2	1.8	3.5	2.0	0.5	2.2	3.3	3.0	2.0	3.5	2.0	**1.8**	**1.0**	1.0	1.0	3.0	1.0	3.0	2.0	0.0	0.0	0.0	2.5	3.0	2.5	3.0	2.0	4.0	4.0	2.0	4.0	2.5
I-27D	*Ability of the project to dismiss employees with cause*	2.0	□	2.0	3.0	2.3	1.0	0.5	1.0	1.4	1.0	0.3	1.0	1.5	3.0	**0.5**	**0.0**	2.0	0.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0	0.5	1.0	1.0	2.0	5.0	3.0	3.0	1.0	5.0	1.5
I-27E	*Rewards for ememplary service*	1.0	□	2.0	4.0	4.0	1.0	1.0	2.0	2.2	2.7	0.3	2.0	4.0	3.0	**2.8**	**4.0**	0.0	2.0	1.5	0.0	1.0	1.0	0.0	0.0	0.0	2.0	3.0	2.5	0.0	0.0	0.0	0.0	1.0	2.5	3.0
I-27F	*Relative salary of an operator compared to a day laborer*	2.0	□	3.7	0.0	0.0	1.0	1.0	3.0	1.6	4.0	3.3	4.0	1.0	2.0	**3.0**	**4.0**	3.0	2.0	3.0	3.0	1.0	1.0	□	2.0	2.0	4.0	0.0	4.0	1.5	1.5	2.0	2.0	2.0	4.0	2.0
I-28	Water User Associations	□	6.5	0.7	1.2	0.5	0.9	0.9	1.2	1.42	2.9	0.7	1.8	2.0	2.9	**1.8**	**2.9**	1.2	1.2	0.8	1.3	0.6	0.3	0.5	0.5	0.5	0.0	0.0	0.0	0.0	3.4	3.7	3.6	3.6	3.7	3.4
I-28A	*Percentage of all project users who have a functional, formal unit that participates in water distribution*	2.5	□	0.0	1.7	0.5	0.0	0.0	1.1	2.02	4.0	0.3	1.0	2.0	4.0	**1.0**	**4.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0	4.0	4.0	4.0	4.0
I-28B	*Actual ability of the strong Water User Associations to influence real-time water deliveries to the WUA*	1.0	□	0.7	1.5	0.8	1.0	1.0	2.0	1	2.3	1.7	2.0	2.0	1.0	**4.0**	**4.0**	2.7	1.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	4.0	4.0	4.0	3.5	3.5	3.0
I-28C	*Ability of the WUA to rely on effective outside help for enforcement of its rules*	1.0	□	0.0	1.7	0.4	3.0	3.0	2.0	0.4	2.5	0.3	2.0	2.0	3.0	**2.5**	**4.0**	1.7	3.0	2.0	4.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	3.5	3.0	3.0	3.0	3.0	2.0
I-28D	*Legal basis for the WUAs*	1.0	□	1.6	0.0	0.4	1.0	1.0	1.0	1.9	2.7	1.3	2.0	2.0	3.0	**2.5**	**0.0**	2.3	3.0	2.0	3.0	2.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	3.5	3.5	3.5	3.5	3.5	3.0
I-28E	*Financial strength of WUAs*	1.0	□	2.3	0.3	0.5	1.0	1.0	0.2	1.8	1.3	0.7	3.0	2.0	2.0	**0.5**	**1.0**	1.3	0.5	0.0	0.5	1.0	0.0	0.5	0.5	0.5	0.0	0.0	0.0	0.0	1.0	3.5	3.0	3.5	4.0	3.8
I-29	Mobility and Size of Operations Staff□																																			
	Operation staff mobility and efficiency, based on the ratio of operating staff to the number of turnouts	□	□	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	**0.5**	**0.0**	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	3.0	3.0	4.0	3.0	1.0	4.0	4.0
I-30	Computers for billing and record management□																																			
	The extent to which computers are used for billing and record management	□	□	1.7	1.0	1.0	1.0	1.0	1.0	3.0	0.7	0.3	3.0	0.0	2.0	**1.5**	**2.0**	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	2.0	1.0	2.0	0.0	1.0	1.0	0.0	0.0	4.0	3.0
I-31	Computers for canal control																																			
	The extent to which computers (either central or on-site) are used for canal control	□	□	2.0	0.0	0.5	3.0	1.0	1.0	2.0	1.3	0.0	0.0	0.0	0.0	**3.0**	**0.0**	0.0	3.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0

Indicator Label	Indicator Name	Weighting Factor	Sum of weighting factors	Malaysia					Thailand		Indonesia		Phi-lip-pines	Viet Nam		**China**		India				Nepal		Pakistan			Iran		Mo-roc-co		□DR	Colombia		Mexico		Tur-key
				MADA	KERIAN KUMP	Penang	Muda*	Kemubu*	Lampao*	Nam Oon	Lodoyo	Lakbok	MARIIS**	Dau Tieng	Cau-Son, Cam-Son	**Zhanghe**	**Jiamakou**	West Krishna Audhra Pradesh	Majalgaon*	Dantiwada*	Bhakra*	SMIP	Narayani	AkramWah	Fuleli-Guni	Ghotki	Dez*	Guilan*	Benl Amir*	Office du Niger*	Rio Yaqui*	Coello*	Saldana*	Cupatitzio*	Rio Mayo*	Sehan*
□INDICATORS THAT WERE NOT PREVIOUSLY COMPUTED																																				
□THESE INDICATORS REQUIRE THE INPUT OF VALUES (0-4) IN EACH OF THE BOXES□																																				
I-32	Ability of the present water delivery service to individual fields, to support pressurized irrigation methods	□	3	0.0	0.6	2.9	1.7	1.7	0.7	0.0	0.1	0.6	0.0	1.0	0.3	**1.8**	**1.7**	0.0	0.8	0.8	0.7	0.7	0.0	0.3	0.3	0.3	1.5	1.7	2.0	3.0	2.7	3.0	2.0	2.2	2.8	0.0
I-32A	**Measurement and control of volumes to the field** 4 – Excellent volumetric metering and control; 3.5 – Ability to measure flow rates reasonably well, but not volume. Flow is well controlled; 2.5 – Cannot measure flow, but can control flow rates well; 0 – Cannot control the flow rate, even though it can be measured	1.0	□	0.0	0.0	2.8	2.5	2.5	2.0	0.0	0.3	1.0	0.0	0.0	1.0	**2.5**	**2.0**	0.0	2.5	2.5	2.0	1.0	0.0	0.0	0.0	0.0	2.0	2.0	3.5	2.0	2.0	2.5	2.0	2.5	3.0	
I-32B	**Flexibility to the field** 4 – Arranged delivery, with frequency, rate and duration promised. All can be varied upon request; 3 – Same as 4, but cannot vary the duration; 2 – 2 variables are fixed, but arranged schedule; 0 – Rotation	1.0	□	0.0	0.7	3.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.0	0.0	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	3.0	3.0	2.0	2.0	2.5	
I-32C	**Reliability to the field** 4 – Water always arrives as promised, including the appropriate volume; 3 – A few days of delay occasionally occur, but water is still very reliable in rate and duration; 0 – More than a few days delay	1.0	□	0.0	1.0	3.0	2.5	2.5	0.0	0.0	0.0	0.3	0.0	2.0	0.0	**3.0**	**3.0**	0.0	0.0	0.0	0.0	1.0	0.0	1.0	1.0	1.0	2.5	3.0	2.5	3.0	3.0	3.5	2.0	2.0	3.0	
I-33	**Changes required to be able to support pressurized irrigation methods**	□	2	0.2	0.5	1.4	2.8	2.0	0.5	0.83	1.7	1.7	0.0	2.0	1.8	**2.8**	**1.7**	0.0	1.5	2.8	0.5	1.0	0.5	1.5	1.5	1.5	1.5	2.3	1.0	2.8	1.5	3.3	1.5	1.3	3.0	0.0
I-33A	**Procedures, Management** 4 – No changes in water ordering, staff training, or mobility; 3.5 – Improved training, only. The basic procedures/conditions are just fine, they just are not being implemented to their full extent; 3.0 – Minor changes in water ordering, mobility, training, incentive programs; 2.0 – Major changes in 1 of the above; 1 – Major changes in 2 of the above; 0 – Need to completely revamp or convert almost everything	1.0	□	0.3	1.0	1.0	3.0	2.0	0.0	1.1	1.0	1.0	0.0	2.0	1.0	**3.0**	**1.0**	0.0	1.0	3.0	0.0	1.0	0.0	1.0	1.0	1.0	0.5	2.5	1.0	2.5	1.0	3.5	2.0	0.5	3.5	
I-33B	**Hardware** 4 – No changes needed; 3.5 – Only need to repair some of the existing structures so that they are workable again 3.0 – Improved communications, repair of some existing structures, and a few key new structures (less than US$300/ha needed), OR…very little change to existing, but new structures are needed for water recirculation; 2 – Larger capital expenditures – US$300 – US$600/ha; 1 – Larger capital expenditures needed (up to US$1 500/ha); 0 – Almost complete reworking of the system is needed	1.0	□	0.0	0.0	1.8	2.5	2.0	1.0	0.4	2.3	2.3	0.0	2.0	2.5	**2.5**	**2.0**	1.0	2.0	2.5	1.0	1.0	1.0	2.0	2.0	2.0	2.5	2.0	1.0	3.0	2.0	3.0	1.0	2.0	2.5	

Indicator Label	Indicator Name	Weighting Factor	Sum of weighting factors	Malaysia					Thailand		Indonesia		Philippines	Viet Nam		**China**		India				Nepal		Pakistan			Iran		Morocco		▯DR	Colombia		Mexico		Turkey
				MADA	KERIAN KUMP	Penang	Muda*	Kemubu*	Lampao*	Nam Oon	Lodoyo	Lakbok	MARIIS**	Dau Tieng	Cau-Son, Cam-Son	**Zhanghe**	**Jiamakou**	West Krishna Audhra Pradesh	Majalgaon*	Dantiwada*	Bhakra*	SMIP	Narayani	AkramWah	Fuleli-Guni	Ghotki	Dez*	Guilan*	Benl Amir*	Office du Niger*	Rio Yaqui*	Coello*	Saldana*	Cupatitzio*	Rio Mayo*	Sehan*
I-34	**Sophistication in receiving and using feedback information.** This does not need to be automatic. 4 – Continuous feedback and continuous use of information to change inflows, with all key points monitored. Or, minimal feedback is necessary, such as with closed pipe systems.; 3 – Feedback several times a day and rapid use (within a few hours) of that information, at major points.; 2 – Feedback once/day from key points and appropriate use of information within a day; 1 – Weekly feedback and appropriate usage, or once/day feeback but poor usage of the information; 0 – No meaningful feedback, or else there is a lot of feedback but no usage.	▯	▯	3.0	1.5	1.6	3.0	2.0	1.0	1.0	1.0	0.7	1.0	2.0	0.5	**3.0**	**2.0**	0.0	3.0	3.0	1.0	1.0	0.0	2.0	2.0	2.0	1.0	2.0	1.0	1.0	1.0	1.5	1.5	0.0	2.5	
▯SPECIAL INDICATORS THAT DO NOT HAVE A 0-4 RATING SCALE																																				
I-35	**Turnout density** Number of water users downstream of employee-operated turnouts	▯	▯	15.7	21.7	4.0	▯	▯	▯	4.4	45.0	83.7	94	15	150	**12.5**	**0.0**	25.0	▯	▯	▯	100	6000	30	30	30▯										
I-36	**Turnouts/Operator** (Number of turnouts operated by paid employees)/(Paid Employees)	▯	▯	0.6	3.1	1.6	▯	▯	▯	17.19	1.0	0.8	3.6	0.7	0.6	**1.5**	**2.9**	0.1	▯	▯	▯	0.3	0.3	0.0	0.0	0.0										
I-37	**Main Canal Chaos** (Actual/Stated) Overall Service by the Main Canal	▯	▯	0.9	0.9	0.9	▯	▯	▯	0.96	0.7	0.6	0.75	1.10	1.00	**0.8**	**0.91**	0.6	▯	▯	▯	0.83	0.28	0.48	0.42	0.42										
I-38	**Second Level Chaos** (Actual/Stated) Overall Service at the most downstream point operated by a paid employee	▯	▯	0.8	1.1	1.1	▯	▯	▯	0.82	0.5	0.7	0.50	1.00	0.50	**0.7**	**0.90**	0.4	▯	▯	▯	0.48	0.30	0.31	0.31	0.42										
I-39	**Field Level Chaos** (Actual/Stated) Overall Service to the Individual Ownership Units	▯	▯	0.8	0.8	1.0	▯	▯	▯	0.72	0.7	1.1	0.71	0.90	1.75	**0.6**	**0.91**	0.3	▯	▯	▯	0.60	0.33	0.55	0.55	0.57										

Note:

- The values showed in this table is a true value of indicators (not weighted value of indicators)
- For the data from series 19 (old version), the name with * , there is no data of indicator No. I-16, I-20 to I-25 and I-35 to I-39 (blue hilighted). And the value of indicator I-7 (or I-9 in old version) was different from new version (yellow hilighted).
- For MARIIS Project; there is no information in third level canals as the information is in main, second and final deliverly level.

Participatory management and water users' associations

Feng Guangzhi[1]

1. Understanding the meaning of participatory management

1.1 The need for transparency

On one occasion, during the construction of a new rural drinking water project, the local government was responsible for every activity, including investment, initiation and construction. However, after completion, several months later the project ceased because no one was paying for electric power charges. Farmers wondered why the government did not continue with such a useful facility. Elsewhere, in order to support water-saving activities, the government subsidized the building of micro-spray irrigation units for a rural area. After bidding, a company was awarded construction rights. When performing manual labour, the villagers requested cash rewards because the company was making the profit. It can be concluded that in both cases farmers only partly participated — neither the government nor the farmers realized their own roles correctly. The government addressed issues that should have been decided by the farmers. Farmers became spectators or passive participants due to lack of transparency with regard to rights and property.

1.2 The meaning of participation

Now it is not disputed that farmers should participate in rural development. However, there are questions on the definition of participation and ways in which to participate. Many people consider that projects which were built through farmers' labour and funds should involve farmers during subsequent rural water development activities. There should be no need to emphasize participation because farmers are always participants.

As a modern scientific concept, participation does not only mean taking part in an activity; more profoundly it is related to conferring, autonomy and democracy. Apart from being a necessary component of socio-economic development, participation is the main approach to improving irrigation district management, juxtaposed by rural development and environmental protection. Participation is unlikely without conferring, autonomy and democracy, descriptions of which are provided hereunder.

Conferring: Entrusting or transferring rights of public management and service assumed by the government to water users' associations (WUAs) in irrigation projects (the transfer of management rights).

Autonomy: Realizing rural and community empowerment. For an irrigation district, this allows water users to manage projects, irrigation and drainage matters and to exercise their rights.

Democracy: Establish an equitable and cooperative relationship between irrigation agencies and WUAs. Government personnel or irrigation management agencies should listen to farmers' opinions and respect their innovative spirit in order to absorb indigenous information.

Participation: Undertake responsibilities while exercising rights. Participation should be generic, not simply related to water-related activities and should include more extensive areas of societal development by including every stakeholder.

1.3 Law and policy foundation

China's constitution stipulates that national affairs belong to the people who should participate in their governance. In 1994, the Chinese Government's twenty-first century agenda stipulated that the implementation of the sustainable development strategy should be based on approval, support and participation among citizens to determine the strategy's success.

[1] President, China Irrigation Schemes' Association.

In recent years, the central government has started to promote village autonomy. The central government also allows farmers to be decision-makers in local affairs. Essentially there is a need to transfer various rights to farmers.

The Chinese Government has always believed in the power of mass support, including the theory of participation. So the concept of "participation" was never imported. However there are characteristic differences in "participation" as a feature of modern public management. Currently most issues appear to be decided by the government and work which could be accomplished by farmers is delegated elsewhere. Moreover farmers' participation can occur because the government requires it and it is not provided on a voluntary basis, thus being passive participation at best.

1.4 Conferring

According to the 16th Central Committee of the Communist Party of China, the main constituents of "conferring" include rights related to:

- Information pertaining to all kinds of rural water affairs that benefits users, such as rainfall forecasts, water diversion plans, water pricing and expenditure in the irrigation district.
- All aspects of farmers' daily production, including water management for rural development. This includes listening to users' opinions and inviting them to participate in project planning, construction quality control, inspection and maintenance. Currently water charges are determined by the government and users' opinions are not sought. However there is a degree of farmers' participation in decision-making.
- The management of small rural water projects, which local governments should not or cannot run properly; management rights should be entrusted to WUAs or countryside committees.
- Monitoring the construction and management of small water projects administered by local collectives; participating in the supervision of large- and medium-scale irrigation districts and all other water affairs related to farmers' interests.

2. The development of water users' associations in China

2.1 Development status

In the middle of the 1990s, pilot WUAs were introduced under a World Bank loan. There are now more than 20 000 associations in China, which control 16.5 million acres of irrigated area; 56 million farmers participate. The WUAs are located in 28 provinces and municipalities. In 2005, the Ministry of Water Resources, the State Development and Reform Planning Commission and the State Civil Ministry jointly issued "Opinion Regarding Strengthening the Construction of Water Users Associations", which provides strong policy support. The situation for WUAs is steadily improving.

2.2 Achievements

- The problem of management of tertiary canals in large- and medium-scale irrigation districts has been resolved (in this context the same applies to small rural water works as well).
- Better analysis of supply and demand, increased water revenue, improved fiscal status of agencies in irrigation districts.
- Reduced fee appropriation and misuse by rural grassroots organizations; the farmers' burden has been alleviated.
- Improved farmer awareness on water saving; irrigation water conservation promoted.
- Improved facility maintenance.
- Better water use management in the field; conflicts have been reduced; town governments have fewer constraints.

3. Main experiences

Experience has revealed the need for:

- Attention and support by local governments.
- Dissemination, training and demonstrations.
- Autonomy and democracy.
- Fine-tuning of auxiliary projects.
- Guaranteed funding.
- Good leaders and an effective supervision system.
- Action suitable to local circumstances.

4. Issues

- Unbalanced development: Some groups from grassroots organization do not understand or support farmers' participation. This makes registration difficult.
- Some WUAs were established through officialdom and function too bureaucratically.
- A number of facilities are too old or in a state of disrepair. The WUAs cannot afford upgrading or maintainenance costs; operational funds are insufficient and personnel are not competent.

5. Misconceptions about water users' associations

"WUAs are a foreign innovation and do not belong in China": Irrigation in Dujiangyan and elsewhere (e.g. Zhuji City, Zhejiang Province) has sourced farmers' inputs ("Official Weir" and "Farmers' Weir") for thousands of years; thus the notion of "water associations" has existed for a long time. WUAs are both foreign and domestic concepts.

"Special agencies via rural water management groups provide highly efficient direct management of irrigation districts, WUAs are not necessary": Currently, some irrigation districts under government supervision directly control field irrigation via tertiary canals; consequently efficiency is lower and the cost is greater.

"There is no need to establish WUAs due to the presence of tertiary canal management committees and rural water management groups": According to law, all such organizations must be registered, or they cannot be protected by law. Traditional rural water management organizations should be gradually transformed into formal WUAs.

"Farmers are not competent enough to undertake WUA tasks because of their lack of skills and the complex situation in countryside": Farmers' competence and skills are much higher today than in the past. Many autonomous water management organizations lasted for hundreds or even thousands of years, so we can do better today with the modern technology available.

"WUAs, without exception, cannot control affairs well, the only option is to transfer management to the private sector": The public nature of a rural water project determines that it cannot become a profit-making venture through the private use of public resources and infrastructure. Even in highly industrialized countries, such as the United States and Japan, WUAs or similar associations are part of irrigation management structure.

6. Prospects and suggestions

- Improve laws, define the legal status of WUAs.
- Improve policies, resolve funding problems for infrastructure upgrades through WUA consolidation and operation; clarify local government duties and responsibilities towards WUAs.

- Strengthen regulations in order to realize standardization and institutionalization.
- Improve farmers' water management capacity through information dissemination, training and experience sharing.
- Conduct demonstrations.
- Thoroughly research theory and policy on water users' participation.

Modernization of irrigation canals: The Uttar Pradesh Water Sector Restructuring Project, India

M.K. Goyal[1]

1. Background

Uttar Pradesh, India's fourth largest state, is endowed with bountiful water resources, fertile soil and a favourable climate. The Yamuna, Ganga, Ramganga, Gomti, Sarda, Ghaghra, Rapti, Gandak, Sone, Ken and Betwa are all perennial rivers. Agriculture and related activities is the dominant sector in the state's economy contributing about 40 percent of its GDP. Though the state is seemingly endowed with abundant water resources, both surface and underground, challenges in their allocation for various uses owing to the growing population and increasing demands by other sectors will limit its availability for agriculture. Water is one of the crucial elements of development planning. The planning of this resource therefore has to be guided by holistic state development which takes into account geographical conditions, hydrological status, water rights, allocation priority, engineering possibilities and other specific needs. Irrigation is fundamental to agricultural growth, so judicious planning, development and management of water are at the core of sustainable state development.

The irrigated agriculture sector has performed suboptimally during the past two decades. Against a desired growth rate of between 2.5 to 3 percent or even higher, the growth rate in the agriculture sector has been only 1 percent, approximately. Sustainable development in irrigated agriculture will not only increase food production but will also substantially enhance the income of farm households and contribute significantly to poverty alleviation.

Present growth trends in the state's population, currently touching 160 million, development demands in general, increasing pressure on drinking and domestic water supply and ecological conservation will place considerable pressure on the state's water resources. Allocation to the irrigation sector, so far the principal user, is likely to be reduced. Improvement in irrigation water management technology and use of modern methods of water application will have to be adopted to improve the performance efficiency of the existing systems for optimal benefits.

2. Objectives

The Government of Uttar Pradesh adopted the State Water Policy in May 1999. The broad objectives of the policy are:

- Ensure preservation of scarce water resources and optimize the utilization of available resources.
- Generate qualitative improvement in water resource management, which should include users' participation and decentralization of authority.
- Maintain water quality, both surface and underground, to established norms and standards.
- Promote project formulation, to the extent possible, in the context of basin or sub-basin management, treating both surface and groundwater as unitary resources, and ensuring multipurpose use of water resources.
- Ensure ecological and environmental balances while developing water resources.
- Promote equity and social justice among individuals and user groups in water resource allocation and management.

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- Ensure self-sustainability in water resource development.
- Ensure that flood management and drainage are integral features of water resource development.
- Provide a substantive legal framework for management.
- Provide a Management Information System (MIS) for effective monitoring of policy implementation.
- Promote the development of research and training facilities in the water resource sector.
- Provide mechanisms for conflict resolution among various users.

3. Development concepts

The development concepts of the Uttar Pradesh Water Sector Restructuring Project (UP–WSRP) are:

- To set up an enabling institutional and policy framework for water sector reform in the state for integrated water resource management.
- To initiate irrigation and drainage sub-sector reforms in the state to increase and sustain water and agricultural productivity.

The UP–WSRP is being implemented by the Uttar Pradesh Irrigation Department (UPID) and proposed investment would contribute to:

- The establishment and operationalization of apex water resource institutions critical for the holistic planning and allocation of water resources following a river basin/sub-basin approach.
- The establishment and operationalization of a State Water Tariff Regulatory Commission to rationalize tariff setting.
- Institutional reforms and re-engineering of business procedures in the irrigation sector.
- The piloting of replicable options for basin planning and integrated water resource development and management.
- The rehabilitation and modernization of irrigation systems covering about 300 000 ha and of associated drainage networks in two selected sub-basins; the piloting of replicable management options for sustained irrigation and drainage operations.
- Feasibility studies and preparation of activities for the next phase of the programme.
- The coordination of project activities.

The UP–WSRP would initiate the reform programme and develop replicable reform models through large-scale institutional reforms and investment in selected pilot sub-basins of the Ghagra–Ganga Basin to improve the living standards of poor farm households. The main agro-economic problems of the schemes in these basins are:

- Low irrigation water deliveries and low agricultural production; consequently low farm household income.
- Suboptimal cropping intensity with no cultivation of high value cash crops.
- Land degradation by waterlogging and salinity, exacerbated by seepage from the canal network.

4. The irrigation system

Most of the large irrigation networks constructed more than 100 years ago are now performing suboptimally and need rehabilitation and modernization. The Jaunpur Branch Sub-basin (JBS) has been selected as the area in which reforms are to be piloted. The Sarda Sahayak Project, of which the JBS is a component, was framed in 1967, commissioned in June 1974 and completed in stages up to 2000. The project envisaged not only augmenting supplies in the lower reaches of the old Sarda Canal System, but also extending irrigation facilities to large areas in central and eastern parts of the state. For this purpose, a 400-m-long barrage was constructed across the Sarda River in Lakhimpur Kheri District to supply 650 m^3/s via the 259-km-long Sarda Sahayak Feeder Canal. To complement irrigation water requirements during the low flow months (October to mid-June) of the Sarda River, a further 480 m^3/s is diverted from the Ghagra River to the Sarda River by a 28.7 km link canal. A 716-m-long barrage across the Ghagra at Khatarnia Ghat in Bairaich District was constructed to feed 480 m^3/s water into Sarda Sahayak Canal (the feeder channel). Supplies are also augmented by the Ghaghra, Tanda, Dohrighat and Dalmau lift canal systems and provide irrigation to an additional 1 520 000 ha in central and eastern UP.

5. Present status

The culturable command area (CCA) of the Jaunpur Branch is about 275 000 ha with a designed *rabi* irrigation intensity of 48 percent and *kharif*[2] intensity of 67 percent. Due to the twin problems of heavy silting and poor maintenance, the canal systems are not able to carry the design discharge and are therefore performing suboptimally. In some areas farmers have installed shallow tubewells, taking advantage of advances in tubewell technology. Groundwater is presently used in the private domain of the canal command area and there is an unorganized grey market for this resource. Farmers usually use the groundwater for augmentation of water supply to their fields.

The Jaunpur Branch starts from the Haidergarh Branch at km 22.98. The Haidergarh Branch starts from the Main Feeder Channel at km 171.50. For effective functioning of the Jaunpur Branch, the Haidergarh Branch has to be rehabilitated and modernized from km 0 to km 22.98. This channel is constrained by silting along its entire length, particularly in the first six kilometers, as there are curves in the alignment and the longitudinal slope is gentle. The silt ejector at the head of the Sarda Sahayak System currently has very low efficiency and during the *kharif* season when the silt content in the feeder exceeds 4 000 ppm, the feeder channel is closed.

The Jaunpur Branch (119.45 km) is in poor condition; the banks are lower than the one-meter design standard, there are no counterberms and in several locations the structures are in disrepair. The condition of distributaries and minor canals is similarly poor. The Jaunpur Branch is reported to deliver a discharge of about 85 m^3/s against the design discharge of 123.2 m^3/s. There are no discharge-measuring devices in the minor canals. The outlets are not based on scientific design principles and cannot be found in some locations. Farmers have made cuts in the system or placed their own outlets without considering levels; this has led to inefficient operation. There are direct outlets to farmers' fields from branches and distributaries

The principal reasons for low irrigation system performance in the Jaunpur Command are:

- Inadequate water supply.
- Very poor distribution efficiency in terms of space, time and flexibility.
- Land degradation (waterlogging and salinity).

These deficiencies affect the irrigated agricultural productivity of the project area in general.

Water availability: Available water resources are spread over a wide area. This gives rise to two constraints: Unit discharge and the total allocated water volume. The design discharge is 123.2 m^3/s for an irrigable area of 275 000 ha, implying a unit discharge of 0.45 liter/s/ha. This discharge is very small considering the water requirements of the potential cropping pattern in the peak seasons. Out of this amount, it is estimated that 35 percent of the water is lost by percolation from the branches, distributaries, minor canals and field ditches. Thus the aforementioned discharge does not reach the fields. In reality, because of uneven water distribution, head reaches receive a larger application while tail reaches are in deficit.

[2] *rabi/kharif*: winter and summer crop-growing seasons respectively.

Sedimentation problems: The water availability potential of the Jaunpur Command cannot be realized at present due to decreased canal conveyance caused by excessive sedimentation. The main reasons for sedimentation are:

- Operational failure of the sediment ejector at the headworks of the feeder canal. This results in accumulation of silt in the feeder canal, reduced water availability to the Jaunpur Command and further deposition in its irrigation network.
- Inadequacy of the escape structures on the main branch canals which were designed to provide: (1) Canal safety (preventing dangerous water levels in excess of the feeder supply level [FSL]) and (2) sediment flushing.
- Deferred desilting in the vicinity of the Jaunpur Command regulator gates and canal dredging, thus exacerbating the loss of canal conveyance capacity. The canal cleaning period is also confined to the short periods between the irrigation seasons. Even desilting immediately upstream and downstream of the regulator gates by compulsory or voluntary farmer labour is not undertaken, although it could provide major seasonal relief and raise canal discharge potential.

Groundwater balance: The groundwater potential is not utilized except in canal tail-end areas with zero or hardly any canal water delivery. At present, the recharge of groundwater from canal seepage losses, from rice fields and other irrigation losses exceeds the outflow from the aquifer. Since its commissioning in 1974, a gradual rise in groundwater levels has been observed in the vicinity of the canals. In much of the project area, the impact of irrigation over many years has caused the groundwater table to rise near or up to the root zone. Waterlogging is the most challenging problem causing salinity, land degradation and poor agricultural production and productivity.

Groundwater levels: As illustrated in Figure 1, large expanses with groundwater levels less than 2 m below the surface occur along the Jaunpur Branch and along large distributary canals, especially at the system head where water supply is abundant. The situation is exacerbated during the *kharif* season when rainfall is abundant.

Land degradation: Water tables are rising, especially near canals and cause waterlogging and consequent salinization/sodicity damage, especially in areas with high seasonal rainfall or rising groundwater levels.

6. Water distribution and operation

The Jaunpur Command was designed for different *kharif* and *rabi* optimum supply levels depending on seasonal (run-of-the-river) water availability at the feeder canal headworks. Now the canal runs at the same FSL in both irrigation seasons. During the *rabi* season, however, a time-based rotation has been introduced as the canal head discharge declines. The following Jaunpur Command operational problems have arisen:

- As a result of wide spacing between the cross-regulators and using variable discharges in the canal, there is a wide fluctuation of canal water surface elevations. When flows are further reduced by uncontrolled siltation in the feeder canal and in the Jaunpur system, head regulation is insufficient for effective water deliveries when the available discharge in the Jaunpur Branch Canal and its distributaries is low (especially when flows to the Haidergarh Branch are rotated with the two upstream commands on the feeder). This in turn leads to low canal velocities and inadequate head and supply levels in the minor canals and reduced delivery to field outlets, especially at the minor tail ends. The problem of minor canal tail-end water levels is further exacerbated by siltation.
- Unreliable water deliveries result from no technical options for head regulation of flow to minor canals, organizational limitations and a bare minimum of maintenance needed to ensure some water delivery. Thus farmers damage minor canal inlet gates (to increase inflow), and illegally divert water at the expense of others; consequently upstream–downstream social conflicts among irrigators within the domain of the minor canals occurs.

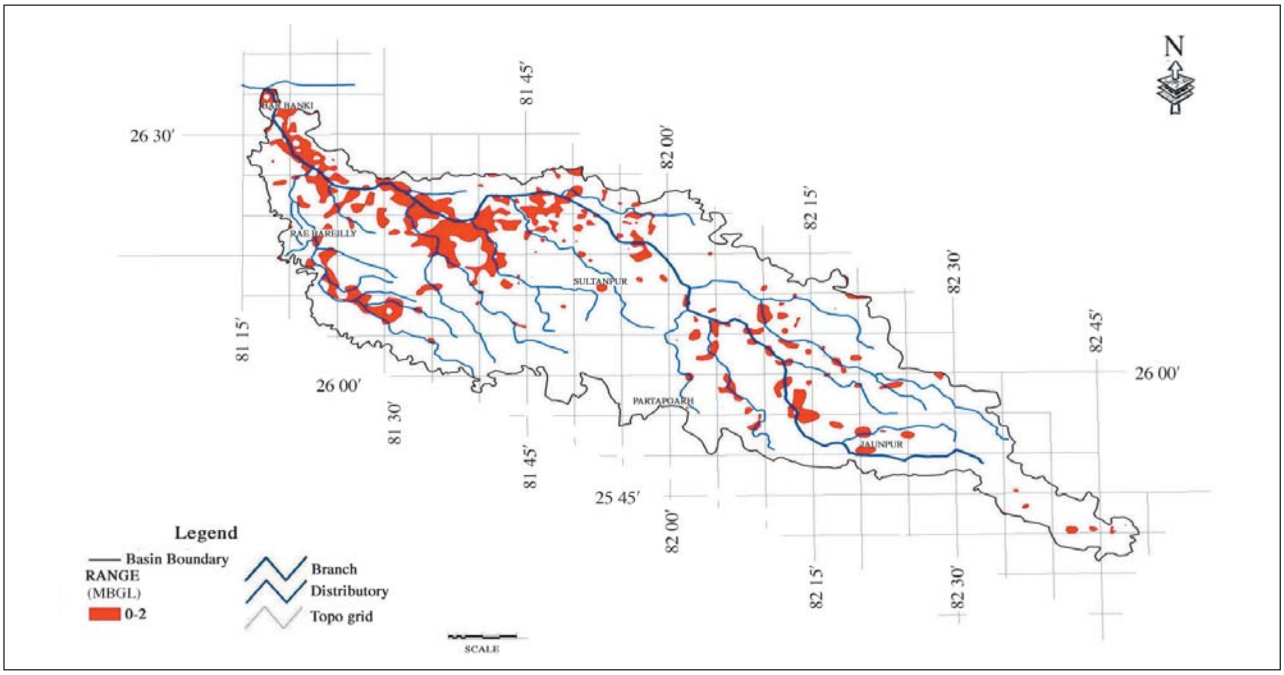

Figure 1. Water table depths of 0–2 m in Jaunpur Basin

Plate 1. Land degradation near a branch

7. Redesign of irrigation systems

Redesign is aimed at providing reliable water delivery and piloting of replicable management options for sustainable irrigation and drainage operations based on community priorities and participation. Community involvement would be facilitated by the formation and operationalization of about 400 water users' associations (WUAs) through extensive consultation and joint canal network walkthroughs. Development of WUAs is to proceed through three stages of responsibility: (1) Water distribution; (2) management of minor canals; and (3) revenue collection. In addition, modernization of these systems to cater to future demands and new management infrastructure is necessary; for instance the installation of measuring devices and other advanced tools to monitor the performance of the irrigation and drainage systems. Upgrading the irrigation system to achieve the primary physical project objective will include the following activities:

- Improvement of canal conveyance and water regulation with emphasis on participatory design for minor canals.
- Utilizing groundwater potential.
- Water harvesting.

8. Improving the irrigation system

Canal system improvements include: (1) Improving water control and efficiency of water distribution in the main systems; (2) improving water control within the domain of the WUAs (minor canals). These improvements are described hereunder.

Sedimentation control: Completely solving the sedimentation problem upstream of Haidergarh Regulator is not expected. Even if the feeder canal's silt ejector is restored to an assumed design efficiency of 20 percent and removes bed-load sand, the residual silt and fine sand will still be transported to the downstream commands. Thus, unless there is heavy annual maintenance, degradation of the conveyance capacity in Jaunpur Command will continue. The sedimentation problem could be addressed by the following options:

- Reduction of the silt load in the head of the feeder canal.
- Reduction of local accumulation of silt near regulator head gates by appropriate gate operation and annual removal.
- Removal of silt by a silt trap close to the head of the Haidergarh Branch, and routine desilting.

Silt trapping downstream of the Haidergarh Regulator: The proposed silt trap consists of two parallel channels. The flow is diverted between the two settling basins with a wetted cross-section bigger than the cross-section of the Haidergarh Branch; this reduces velocity so sediments precipitate. Periodically, one of the two basins is closed so that accumulated silt can be removed and disposed. The expected advantages of the trap are: (1) Significant relief of the silting problem in the entire Jaunpur Command; (2) desilting can proceed while the canals are in operation.

Geometry: The proposed silt trap will consist of two sedimentation chambers, the size of which will be determined by model testing. The entry and delivery of water will be controlled by two sets of headless change-over gates. Well-designed transitions will be provided at upstream and downstream ends. The length, width and depth of the sedimentation chambers will be determined so the concentration of silt particles in the water flowing downstream to the silt trap will be within the limits of easy conveyance. The various dimensions of these settling basins will depend on the concentration of silt, particle size distribution, discharge, settling velocity, period of operation and safe limits for silt concentration in the downstream flow. Preliminary schematics are given in Figure 2.

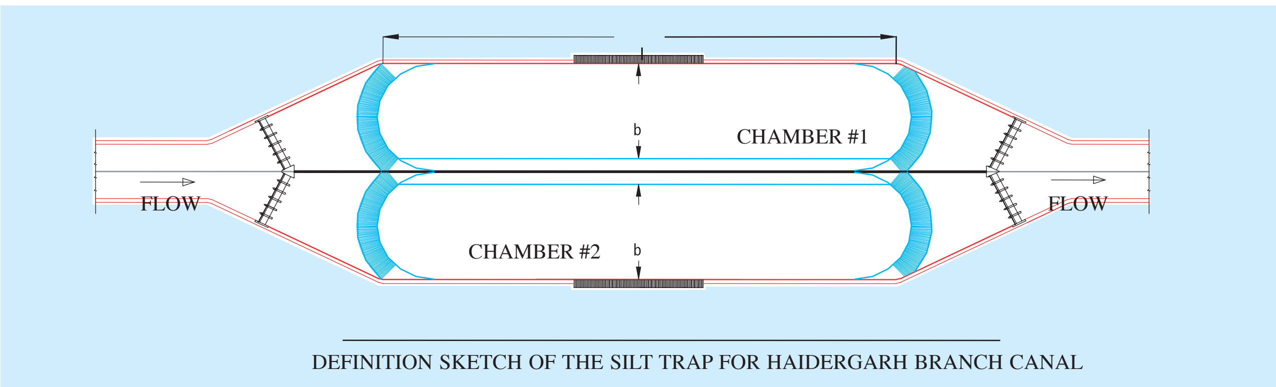

Figure 2. Silt trap for Haidergarh Branch Canal

Structure: The transition banks and outer sides of settling chambers will be concrete tile lined. The dividing wall between the two chambers may be either of re-inforced cement concrete or of brick masonry depending upon the pressure forces. The gate arrangements on both sides of the silt trap will be similar and their type and operation will be the same as for the cross-regulator. The lowered floor and tapered sides of the settling chambers are proposed to be of double concrete tile lining. Necessary care will be taken during designs for the uplift pressure in the floors of the chambers.

Operation: Water will first enter the silt trap through one of the cells and the other cell will remain closed at both ends. After flowing for the planned number of days, when the settling chamber is filled with silt, the exit gates of the second cell will be opened first followed by the entry gates of this cell. When water starts flowing through the second chamber, the entry and exit gates of the first cell will be closed. After settling, all of the deposited silt from the cell will be removed mechanically via earth moving equipment, a conveyer belt arrangement or screw pumps. After cleaning, the first chamber will be ready for use. The second chamber can then be closed and cleaned. This process will continue alternately and will provide an unrestricted time for cleaning and managing the silt without affecting the canal flow.

Disposal of silt: The settled volumes of silt will be removed from the settling chamber and disposed outside the canal banks. Commercial exploitation of the silt volumes will need to be examined in order to derive benefits on a regular basis.

Routine desilting: The feasibility of using floating dredge pumps for silt removal from sensitive locations, such as nearby gates, may be considered. In the absence of effective desilting facilities, sediment that enters the project area should be removed annually by extensive maintenance of distributaries and minor canals.

Improving water control and water distribution efficiency in the main systems: The main components of water control improvement are:

- Elimination of direct outlets.
- Reduction of the distance between cross-regulators to facilitate water elevation control over a wider range of discharges.
- Introduction of automation.

Branch canals: The branch canals will convey water to distributaries only. Water elevation will be controlled only near the distributary gates. This will considerably simplify the operation of the branches and additional cross-regulators may be required. All the direct outlets from Haidergarh Branch and Jaunpur Branch will be disconnected and substituted by either:

- A “clubbed” outlet structure delivering water to the original delivery point.
- Another water source — wells.

The well option would supply water locally to the field channels formerly served by direct outlets. Water from the well to the field channel will be measured. The well will have a connection to the branch canal to allow discharge augmentation. This will allow a degree of freedom between irrigation demand and groundwater control.

Clubbing of direct outlets: There is a number of miniature direct outlets along the branches and distributaries, which flow freely without any means of control or measurement. These outlets cause flooding in the surrounding areas when the water is not needed for irrigation. One of the proposed solutions for the problem of the direct outlets is to “club” them by parallel rolled compacted concrete (RCC) canals. The direct outlets will be disconnected from the parent canals. Instead, the parallel concrete canals will convey water to the field channels located along the branch. The parallel concrete canals will be connected to the parent canals by robust controllable connections.

Master outlet: The flow from the master outlet will be controlled by a gate/sluice valve. The water will be distributed to the RCC canals and to the field channel by a proportional main distribution chamber.

RCC canals: The RCC canals will have three typical sections (Table 1).

Table 1. Sections of RCC canals

Type of channel	Bed width	Full supply depth	Free board	Area of flow "A"	Wetted perimeter	Hydraulic mean radius	Manning's Coefficient "n"
	[m]	[m]	[m]	[m²]	[m]	[m]	
T30	0.30	0.150	0.15	0.04500	0.60	0.0750	0.018
T45	0.45	0.225	0.15	0.10125	0.90	0.1125	0.018
T60	0.60	0.300	0.15	0.18000	1.20	0.1500	0.018

Distribution chambers: Proportional distribution chambers will be constructed at nodes of distribution to field channels. The flow will be distributed to the field channel and to the downstream RCC canal proportionally to the crest width.

Road crossings: Pre-cast RCC slab cover will be provided on the proposed RCC channels at road crossing locations.

Seepage drain crossings: RCC channel-type drain crossings will be constructed in order to traverse the seepage drainage canal.

Distributaries: It is proposed to construct new cross-regulators, duckbill weirs, check drops and crest walls at locations required to maintain a minimum head of 0.3 m aboveground near the outlets to the minor canals under conditions of 50 percent of the maximum designed discharge.

Duckbill weir: The provision of a duckbill weir to maintain the FSL in channels with low discharge is a new concept in this command. The basic design concept is to ensure full supply for water surface elevation, corresponding to full discharge in the distributary canal. For control of water surface elevation, when the discharge is lower than the full supply discharge, long-crested weirs or cross-regulators have to be provided at suitable locations.

With regard to the high concentration of silt, the proposed duckbill weir has been designed as a composite regulator consisting of a duckbill weir associated with conventional sluices. The proposed duckbill weir has the advantages of the conventional cross-regulator and normal duckbill weir, and eliminates the disadvantages of both.

A fixed long-crested weir controls the water level at a given height within relatively narrow limits. The crest length is determined in relation to the discharge to be passed over the weir crest and the control requirement. The length of the crest shall vary according to the tolerances. It is most economical for providing an optimum discharge capacity in relation to the length of the structure. Simplicity of construction and maintenance and operational reliability are the major advantages.

As supplies carry high silt loads, 50 percent design discharge is allowed through sluice gates and a long-crested weir has been designed to pass the remaining 50 percent discharge. The proposed duckbill weir is capable of maintaining the required FSL upstream between canal discharge variations of 50 to 100 percent. The proposed sluice gates are designed to pass 50 percent discharge with maximum waterway width of 1 m. For cross-regulators, more gates with wider waterways will have to be provided. These long-crested weirs control the upstream level changes. They have a W or V shape depending upon the discharge, canal width and the tolerable upstream variation.

Level setting: In a hydraulic study of duckbill weirs, it must be ensured that the structure operates independently from downstream hydraulic conditions. Figure 2 may be used for deciding the sill level.

Here the submergence factor = $\frac{h_2}{h_1}$

If

$\frac{h_2}{h_1}$ <0.6,

then Q = f (h_1)

If

$\frac{h_2}{h_1}$ <0.6,

then Q = f (h_1, h_2)

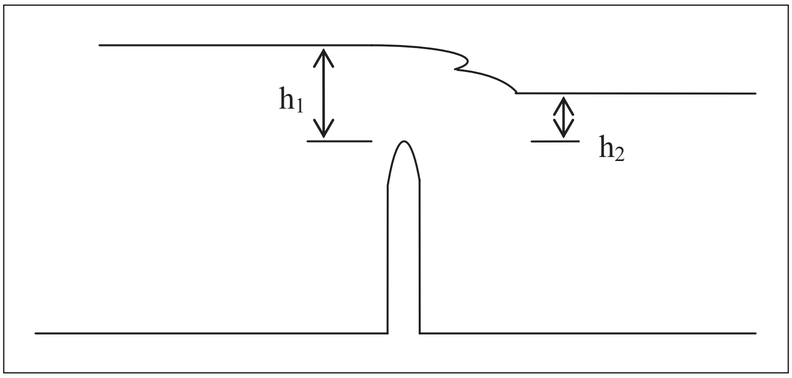

Figure 2. Parameters for establishing the sill level

So, to be insensitive from downstream water elevation, the submergence of a weir should be less than 0.6, to be on the safer side, we have adopted this limit as 0.5 only, i.e. h_2 <0.5 h_1 (downstream level sill level) <0.5 (upstream level sill level).

This condition establishes the minimum acceptable sill level of the weir.

Length of the weir: The design length of the weir is calculated from the standing wave which will occur at the maximum discharge. The length of the weir and width of the sluice gate have been designed according to available head loss at the location in case of design discharge. For lower discharge, upstream control shall be adopted by adjustment of the sluice opening.

The design of the crest for the duckbill weir is almost similar to the design of the crest for a conventional weir; the difference is only limiting the head over the crest to between 10 and 15 cm by providing a long crest, so that variation in upstream FSL is minimal.

The length of the weir sill can then be calculated by applying the following formula:

Q = mB$\sqrt{2g}$ H3/2

Where,

m = 0.4
B = length of crest
g = acceleration (9.81 m^2/s)
H = head on the crest
Q = Design discharge of the canal (m^3/s)

Since the flow over the duckbill weir is known, the length is calculated from:

L = Q / (1.772 x H3/2)

Flow simulation has been developed for the distributary for full, 75 and 50 percent discharge; it is felt that new water elevation control structures are needed to facilitate off-taking minor canals to draw their authorized discharge in case of low discharges in the parent canal. Similar observations were made in discussions with farmers and WUAs during walkthroughs. With regard to farmers' acceptance, a V-type duckbill weir with two 1 × 1.45 m sluice gates has been designed for experimentation at km 8.75 of Tikri distributary.

Regulation and metering: Minor canals in the project area are expected to be managed by WUAs in the near future. Participatory irrigation management will mean that WUA representatives will submit their views on service delivery, present their expectations and approve irrigation management operations. Controllable and measurable inlets to the minor canals will be installed. These inlets will provide the basis for volumetric water charges when these are instituted in future. Calibrated orifice modules (Neyrpic) that enable