

*Advancements in IIMI's
Research 1992*

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Foreword

"Scarcity and misuse of fresh water pose a serious threat to sustainable development and the protection of the environment." This statement was adopted at the International Conference on Water and the Environment, held in Dublin in January 1992 in preparation of the United Nations Conference on Environment and Development (the Rio Conference). The Conference pointed to irrigation as by far the largest single user of water: "Irrigated agriculture accounts for about 80% of water withdrawals in the world. In many irrigation schemes, up to 60% of this water is lost on its way from the source to the plant. More efficient irrigation practices will lead to substantial fresh water savings."

The twentieth century has seen a massive growth in irrigation. About 35 percent of all food is produced on irrigated land, and this is the primary factor enabling mankind to feed an ever increasing population. However, it is not only the population increase that necessitates a raise in productivity of both land and water in irrigated agriculture. Competition for good quality water comes from urban uses of water, such as those for drinking and sanitation, and from industrial use, while both urbanization and industrialization add to the pressure on land.

The need to produce more food with fewer resources requires that performance of irrigated agriculture in terms of water and land utilization improve. To achieve this, irrigation managers, whether at national, system or farm level, will need to work hard to meet the challenge of the future. The International Irrigation Management Institute (IIMI) helps national irrigation agencies and other institutions to improve the management of water resources. IIMI aims to achieve the development, dissemination and adoption of lasting improvements in the performance of irrigated agriculture in developing countries through generating knowledge, strengthening national research capacity in irrigation management, and by supporting the introduction of improved management and policy-making.

Once a year, IIMI's researchers working in some ten countries come together at the Internal Program Review at IIMI Headquarters in Colombo to discuss recent research findings. This volume contains the papers presented at the December 1992 Internal Program Review meetings. Together, these papers give an insight into the wide scope of IIMI's studies as they reflect the geographic diversity of the countries where IIMI works. The topics of the papers range from system performance to institutional performance, where the "institution" is a public organisation or a group of farmers involved in local management of their own system. Other topics discussed at the 1992 meetings include the cost-effectiveness of system rehabilitation, conjunctive management of canal water and pumped groundwater, environmental impacts of irrigation, participatory approach to management, and management information systems.

The common thread running through all these papers is irrigation performance and the potential for its improvement. The challenge for us is to derive lessons of transnational importance and applicability from the many country-specific studies. The papers presented herein give you an opportunity to see how we go about meeting this challenge.

Jacob W. Kijne

Director for Research

International Irrigation Management Institute

October 1993

CHAPTER 1

Irrigation Management in the Fordwah Branch Command Area, Southeast Punjab, Pakistan

Marcel Kuper and Jacob W. Kijne

INTRODUCTION

IN 1989, IIMI-PAKISTAN started research under the Dutch-funded Waterlogging and Salinity Project at three sites in Pakistan's Punjab, where the International Irrigation Management Institute (IIMI) had previously carried out studies on equity of water distribution.

When IIMI started its research under the project, the authors were requested by the Secretaries of the Irrigation and Agriculture Departments to initiate further studies in the area of the Fordwah and Eastern Sadiqia canals in Southeast Punjab. The area is enclosed by the Sutlej River, the Indian border and the Cholistan Desert and is known to be severely affected by salinity and high water tables. Extensive surface and subsurface drainage schemes have been planned for the area, and one is now under construction in an area overlapping the site IIMI selected for its study. As the objectives of the project stipulate that research should be done in areas of incipient waterlogging and salinity, the selected sites are not among the worst affected by salinity or waterlogging in the entire service area of these two canals.

The research objective is to identify possible improvements in irrigation management which may lead to prevention of further land degradation and which could mitigate the effects of salinity on crop production. It is by no means certain that the underlying hypothesis, i.e., improved management can prevent further deterioration, can be demonstrated to be correct. In fact, much of irrigation history indicates otherwise; once water tables are high and secondary salinity has become a source of much reduced productivity, reversal of these trends can only be achieved through the installation of (subsurface) drains for lowering the water table. Salts in the root zone can be leached successfully when water tables have been lowered unless the salinization process proves to be (nearly) irreversible due to sodicity-induced loss of soil structure and very low infiltration rates.

However, soils in the research area are light textured and, over most of the area, capillary rise from water tables is not likely to reach the plant roots. Moreover, there is considerable tubewell development in parts of the area which may be sufficient to maintain the water table at the present depth. The tubewells in the area are mostly privately owned, as the area is not part of a Salinity Control and Reclamation Project (SCARP) which would have entailed the installation of public tubewells. The reason is that the quality of groundwater was judged too saline to justify the cost of installing public wells. This is undoubtedly true for much of the area under the command of the Fordwah and Eastern Sadiqia canals, but, as farmers have found out to their own benefit, it is not true for the riparian zone along the Sutlej, or for the areas close to main canals and distributaries where seepage provides a thin layer of "sweet" groundwater that can be tapped for irrigation.

The tremendous development of groundwater use in irrigated agriculture in the Punjab, through SCARPs and private tubewells, which was initiated to bring down water tables and hence contribute to mitigating problems of waterlogging and salinity, has contributed substantially to the development of secondary salinity, as recent research suggests (VanderVelde and Kijne 1992). Even in areas with low groundwater tables, a process of salinization has been observed to occur. Obviously, these environmental hazards impacting on agricultural production and related to irrigation practices are issues that cut across the traditional compartmentalized institutional structure of Provincial Irrigation and Agriculture Departments and the federal Water and Power Development Authority (WAPDA). This was recognized in the early twentieth century, when the Punjab authorities decided to establish multidisciplinary committees to investigate emerging problems of waterlogging and salinity.

However, at present, precious little information is shared by the various line and research agencies involved in irrigated agriculture on problems of waterlogging and salinity; an indication of the lack of coordination between these agencies on these issues. The present study focuses on the surface irrigation system and the agency directly responsible for operation and maintenance of the system (the Punjab Irrigation Department). The results of this study will, of course, have to be incorporated in a larger framework, linking irrigation management more clearly with problems of waterlogging and salinity that affect crop production.

The paper describes system performance at main-canal level (Fordwah Branch), distributary level (fourteen distributaries that take off from the Fordwah Branch) and eight sample watercourses offtaking from two distributaries in the tail reach of the subdivision. It does so in terms of performance parameters that allow the performance of the Fordwah Branch System to be compared with other systems. The paper also describes the rules and regulations of the engineers of the Irrigation Department who are in charge of system operation, and compares the reality of operation with the nominal rules. Analysis of the results obtained thus far lead to a number of (tentative) suggestions for improvement of the management of the system. These and possibly other management innovations need to be implemented through collaboration of the Irrigation Department and IIMI and their effects monitored, before an answer can be given to the research question posed above.

RESEARCH LOCALE

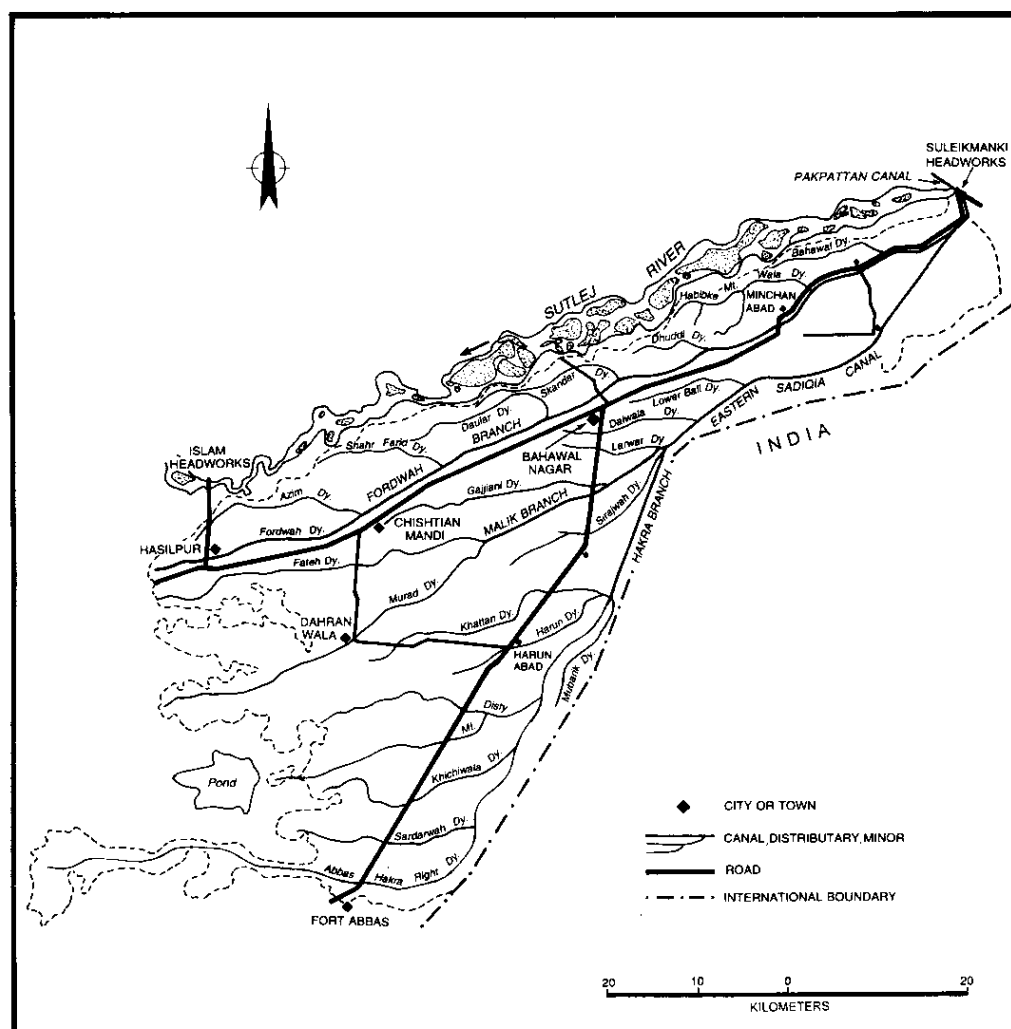
The Fordwah/Eastern Sadiqia area is located in Southeast Punjab and is confined by the Sutlej River in the northwest, the Indian border in the east and by the Cholistan Desert in the southeast (see Figure 1.1). It commands a gross area of 301,000 hectares (ha), of which 232,000 ha are culturable and commendable.

The climate is (semi)arid with the annual evaporation (2,400 mm) far in excess of the annual rainfall (260 mm). The area is part of the cotton-wheat agroecological zone of the Punjab, with cotton, rice and forage crops dominating in *kharif* (summer season), and wheat and forage crops in *rabi* (winter season). In the Fordwah Division, almost a quarter of the area is cropped with rice during *kharif*, mainly in the alluvial areas of the Sutlej. In contrast, the Eastern Sadiqia Division, not forming part of the riparian tract, is almost devoid of rice; only 5 percent of the area is cultivated to rice.

Fordwah Canal and Eastern Sadiqia Canal receive water from the Sutlej at the left abutment of Suleimanki Headworks (Figure 1.1). Both canal commands were developed under the Sutlej Valley Project of 1921, which was launched to increase the reliability of the water supply to low-lying areas along the Sutlej during *kharif*. These areas were previously irrigated by inundation

canals. An additional objective of the project was to supply water to higher lands closer to the Cholistan Desert. The system derived its water originally from Beas, a tributary of the Sutlej, but since partition, when the link canals that connect the rivers of Punjab were constructed, it receives its supply through the link canals from other sources. In kharif, the supplies stem mainly from the Chenab and in rabi, they come from the Mangla Reservoir.

Figure 1.1. The Fordwah/Eastern Sadiqia area in Southeast Punjab, Pakistan.



To distribute the available, limited water supplies over the Fordwah/Eastern Sadiqia System, some areas, which are prone to waterlogging, were labelled non-perennial (i.e., they only receive water during kharif; April–October) and others perennial, with supplies the year round. The non-perennial canals would receive a maximum of 3 allocations per rabi season to “save the wheat crop” (Siddiqi 1991).

There are no public tubewells in this area. However, a large number of private tubewells have been installed, especially towards the river. Exploitation of groundwater in these command areas varies widely, being influenced by access to canal water supplies and limited by the quality of the groundwater.

The total extent of land affected by waterlogging was reported to be around 380 ha (0.2 % of the Culturable Command Area [CCA]) and that affected by salinity was 36,400 ha (16 % of CCA).¹ An increase in the waterlogged area was reported after the 1988 floods. Extensive surface drainage schemes have been planned, and one is now under construction in part of IIMI's research area.

The riparian tract, traditionally commanded by the inundation canals, was inhabited long before the implementation of the Sutlej Valley Project. The farmers in this area, often referred to as "locals," usually have larger landholdings (see Table 1.3 on page 7), make more use of external labor and tend to have a wheat-cotton farming system. The general perception about these locals is that they are uncooperative (Van Waayjen 1991).

By contrast, the farmers in the higher areas that were developed after the introduction of irrigation are locally known as "settlers," and are considered cooperative and more "progressive."

New Developments

During the annual closure period of 1992, a highly publicized province-wide desiltation campaign was launched by the Chief Minister of Punjab. Canals that had been poorly maintained for years were to be upgraded during closure, larger distributaries were to be cleaned by contractors and the smaller distributaries and minors were to be desilted by farmers on a "self-help basis" (Van Waayjen and Bandaragoda 1992). In the Fordwah Division, a large portion of the canal system was actually desilted during the closure period. In addition to this, a number of head-end outlets in distributaries were remodeled to restore their dimensions to the design values.

Research Area

Part of the Fordwah/Eastern Sadiqia Irrigation System, combining perennial and non-perennial canals in its command, was chosen for the study. A distinct hydraulic (sub)unit (Chishtian Subdivision) was selected starting at RD² 199 of Fordwah Branch (oftaking from Fordwah Canal) and going down to the tail at RD 371; it includes the 14 oftaking distributaries. The total length of this stretch of main canal is 52.4 km with 24 direct outlets, and it commands a total CCA of 67,597 ha. The design discharge of Fordwah Branch where it enters the study area is 33 m³/s. In Table 1.1, the main characteristics of the 14 distributaries are presented.

The study area forms part of the Fordwah Division, which falls under the administrative control of the Executive Engineer (XEN), Fordwah Division. The Division is divided into three subdivisions. The study area is located in the tail subdivision, Chishtian, headed by a Subdivisional Officer (SDO), a qualified engineer who is responsible for the operation and maintenance (O&M) of the canals in his charge.

¹ Letter from Superintending Engineer, Bahawalnagar to Chief Engineer, Bahawalpur on 31 January, 1984.

² RD = Reduced Distance from the head of a canal (in 1,000 feet).

The Chishtian Subdivision is further divided into five sections, each headed by a subengineer who is responsible for the day-to-day O&M of a portion of the main canal and its offtaking distributaries (see Table 1.2).

Table 1.1. Characteristics of distributaries in Chishtian Subdivision.

Name of distributary	Offtake at RD (feet)	CCA (ha)	Status	Design discharge (m ³ /s)	Water allocation (l/s/ha)
Daulat	245+600	13,570	NP	5.9	0.38
Mohar	245+600	1,446	NP	1.1	0.49
3 L	245+600	1,166	NP	0.7	0.49
Phogan	267+700	949	NP	0.5	0.49
Khemgargh	281+000	2,032	NP	0.8	0.38
4 L	281+000	877	NP	0.5	0.49
Jagir	297+500	1,604	P	1.1	0.42
Shahar Farid	316+400	10,255	NP	4.3	0.38
Masood	316+400	3,295	P	1.0	0.25
Soda Minor	334+000	4,093	NP	2.2	0.49
5 L	348+800	357	P	0.1	0.25
Azim	371+600	12,199	NP	6.9	0.49
Mehmud	371+600	813	P	0.2	0.25
Fordwah	371+600	14,941	P	4.5	0.25

Notes: P= Perennial
NP= Non-Perennial

Table 1.2. Sections of Chishtian Subdivision.

Section	Area of authority, Fordwah Branch (RD)	Area of authority, distributaries (RD)
Takhat Mal	199–281	Mohar, Daulat (0–63), 3L, 4L, Phogan
Chak Abdullah	281–334	Jagir, Masood, Shahar Farid (0–47), Soda
Chishtian	334–371	5L, Mehmud, Fordwah (0–64), Azim (0–52)
Khemgarh	—	Daulat (63-tail), Shahar Farid (47-tail)
Hasilpur	—	Fordwah (64-tail), Azim (52-tail)

The Fordwah Branch has six control points (cross-regulators) in the Chishtian Subdivision (see Figure 1.2), with distributaries offtaking just upstream of five of these regulators (RD 199, RD 245, RD 281, RD 316 and RD 371). The remaining cross-regulator at RD 353 controls the water

level in the Fordwah Branch itself with only a very small distributary (5 L) offtaking upstream of this control point.

Gauge Readers observe the water levels twice daily at all these control points and the data are transmitted through signalers to the SDO and/or to the XEN via telegraph, and on the basis of these data, the irrigation officers are supposed to take decisions regarding the operation of the irrigation system in their (sub)division.

Two major distributaries offtaking at the tail of Fordwah Branch were studied in more detail to assess the impact of main system performance on the water distribution at secondary level. Eight sample watercourses were selected along the distributaries to study the effects of the operation of the irrigation system at field level. The main characteristics of the eight watercourses are presented in Table 1.3.

Figure 1.2. Layout of Fordwah Branch.

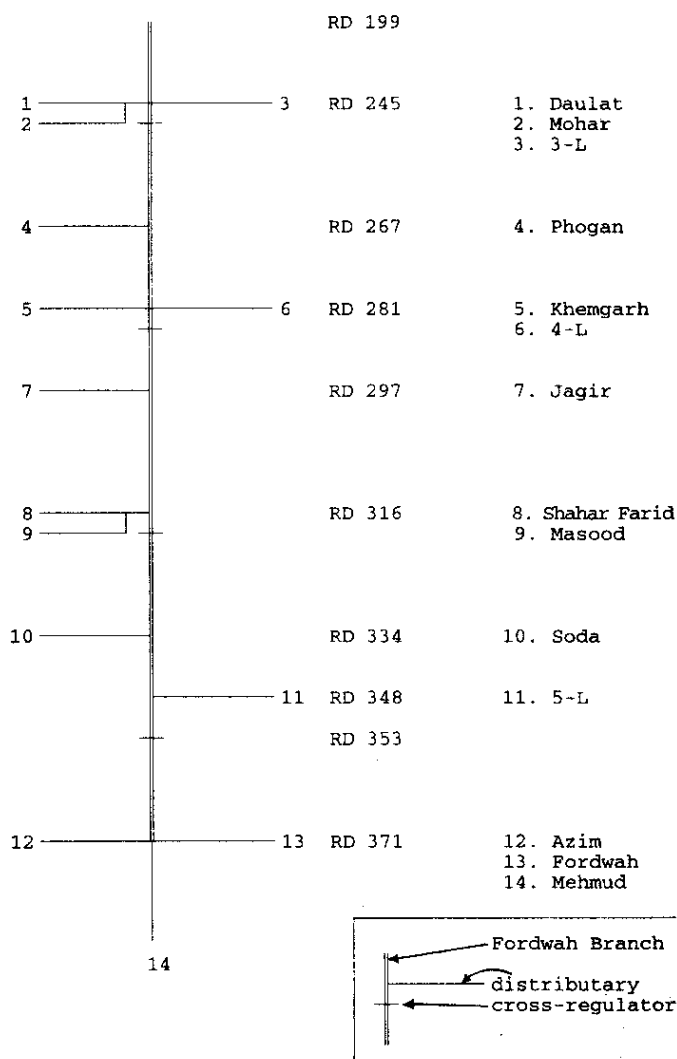


Table 1.3. Characteristics of sample watercourses.

Watercourse	CCA (ha)	Number of landowners	Design discharge (l/s)
Azim 20610 L	119	10	45.9
Azim 43260 L	66	6	26.3
Azim 63620 L	121	14	59.2
Azim 111770 L	119	19	45.9
Fordwah 14320 R	196	46	49.3
Fordwah 46725 R	172	14	44.7
Fordwah 62085 R	133	45	33.4
Fordwah 130100 R	256	42	64.6

Research Methodology

A comprehensive set of primary data was collected from June 1991 to October 1992, focusing especially on rabi 1991/1992 and kharif 1992. To study the performance of the main system, discharges were monitored daily by recording water levels and gate settings at all control points in the Branch Canal and at the inlets to the distributaries downstream of RD 199. This was complemented by interviews with the operating staff using a formal questionnaire.

As part of the study at secondary level, discharges were measured daily along the two sample distributaries, Fordwah and Azim, during kharif 1991 and readings of tail gauges in both distributaries were recorded daily from rabi 1991/1992 onwards. In addition to this, the daily water intakes of sample watercourses were determined.

The operation of tubewells in the command areas of sample watercourses was also monitored daily from June 1991 onwards. Basic socioeconomic data for the sample watercourses, and the status of the *warabandi* ("fixed turns") were obtained through formal questionnaires.

SYSTEM REGULATION — OFFICIAL DIRECTIVES

The Fordwah Canal System, as previously mentioned, is part of the Sutlej Valley Project, which was designed in the 1920s and has been in operation since 1927. The operational objectives, no different from the rest of the Indus Basin Irrigation System, were to allocate and distribute water within as large an area as feasible and as equitably as possible (Bandaragoda and Firdousi 1992), after which farmers would share the water among themselves through a flexible roster of turns called *kacha warabandi*³. This *warabandi* was agreed upon by the farmers themselves, with the Irrigation Department (ID) interfering only when disputes arose. About 20–30 years ago, an increasing occurrence of disputes over the distribution of water in watercourses led the ID to

³ *kacha* = informal, *wahr* = turn, and *bandi* = fixed.

intervene in the vast majority of watercourses and fix an official roster of water turns, *pacca warabandi* (*pacca* = official).

In the design, the area to be irrigated annually was based on the availability of water and the total Culturable Command Area (CCA) with fixed design cropping intensities. In the Fordwah Division, the non-perennial canals have a cropping intensity of 70 percent (35% in kharif and 35% in rabi), whereas the perennial canals have a cropping intensity of 80 percent (32% in kharif and 48% in rabi). The capacities of canals were subsequently determined by multiplying the CCA with the design duty (usually presented in cfs/1,000 acres), and the expected conveyance losses were added. The duty for most perennial-canal distributaries in the Fordwah Branch is 0.25 l/s/ha CCA (3.5 cfs/1,000 acres), while the non-perennial distributaries have a duty of 0.4–0.5 l/s/ha CCA (5.5–7.0 cfs/1,000 acres).

According to the Public Works Department (PWD) Manual (1963), it is customary to treat non-perennial areas more generously in the matter of water allowances during kharif as a kind of compensation for the deprivation of water during rabi. The duties are supposedly, to some extent, based also on the type of soil in the command area, the prevailing climate and the dominant crop. Hence, a second reason for the higher water duties in the non-perennial canals in the Fordwah Division is their location in the rice-cropped, pre-project irrigated, riparian tract.

The implication of fixing the cropping intensities at less than 100 percent in each season is that the actual water allowances for the crops are much higher than the official duties determined for the CCA. When the cropping intensities are taken into account, the water allowances work out to be 0.8 l/s/ha (11.3 cfs/1,000 acres) for perennial and 1.1–1.4 l/s/ha (15.7–20.0 cfs/1,000 acres) for non-perennial canals. Nowadays, however, actual cropping intensities in Punjab are much higher; the Fordwah Division, for instance, achieves an annual cropping intensity of 108 percent, rendering canal water supplies insufficient to cover crop water requirements.

The irrigation system, however, allows some flexibility in the delivery of water. The canal officers (XEN, SDO) can reduce or increase the water supply to main canals and to distributaries according to the (perceived) demand in the command areas. To effect a change in the supply to the system, the ID has established a peer-based communication system wherein the SDOs of the subdivisions of a canal command, starting from the tail of the system, pass on a request, the *indent*, for the desired quantity of water in their subdivisions. In the Fordwah Division, the SDO, Chishtian indicates the desired discharge for his subdivision, through telegraph, to the SDO, Bahawalnagar who places the combined indent of Chishtian and his own division with the SDO, Minchinabad. The SDO of this subdivision, because of its location at the head of Fordwah Canal, is the indenting officer of Fordwah Division who submits the combined indent of Fordwah Division to the XEN in charge of Suleimanki Headworks. The XEN, Suleimanki then tries to match the indents received from all main canals that take off from Suleimanki with the water allowances (for 10-day periods) indicated by the Director, Regulation, based in Lahore. In case of a shortage of water at Head Suleimanki, the shortfall will be shared equally by all divisions. The decision taken by the XEN, Suleimanki is conveyed to XENs and SDOs of the affected divisions.

An indent can be fixed for a definite period, say for a month, or for an indefinite period. Indents are sometimes frequently changed in case of emergencies; for instance, when a breach has occurred in a distributary. The new indent is then quickly passed on via upstream subdivision(s) to the XEN, Suleimanki, who takes action accordingly.

An indent point is fixed usually at the head of each subdivision. In the Chishtian subdivision, it is at RD 199.

Increased cropping intensities and the development of previously unirrigated lands have strengthened the general perception that canal water supplies are insufficient to feed all distributaries simultaneously. Hence, over the past 15–20 years, the ID has introduced rotational programmes within divisions, with subdivisions being given preference with 8–10-day rotations.

In the Fordwah Branch, $3.3 \text{ m}^3/\text{s}$ (116 cfs) or almost 5 percent of the total design discharge of $73.7 \text{ m}^3/\text{s}$ (2,603 cfs) is allocated to direct outlets of the Fordwah Branch, all of which were sanctioned during the last 10–20 years. The larger distributaries of the Fordwah Branch are known to be run at an average discharge which is higher than the design discharge in order to feed the tails. The tail reaches receive less than their share because of several intra-distributary distribution problems, such as water theft, siltation, etc. (Kuper and Strosser 1992).

The XEN, Fordwah Division has introduced an 8-day rotation between the 3 subdivisions of his division, during kharif. Within this 8-day period, first, second and third preferences are given to the three subdivisions. The subdivision that has first preference takes all the water it requires according to its indent, enabling its main distributaries to run at full supply level. Only the requirements of smaller distributaries can be met when the subdivision is in second or third preference. After the subdivision in first preference has taken its full share, the remaining water may be used by the subdivision that has second preference, with the subdivision in third preference taking all the water that is left.

This rotational programme does not apply to water allocation during rabi when only 6 perennial canals in the division, all of which are located towards the tail of Fordwah Branch, draw water. In rabi, water is supplied to Fordwah Branch through the Sadiq-Ford Feeder, which takes off at RD 189 in Eastern Sadiqia Canal and discharges into Fordwah Branch at RD 129. The supply through this feeder is subject to a rotational programme in the Eastern Sadiqia Division, during rabi.

Some 10 years ago, it was felt that available supplies were not sufficient to distribute water simultaneously to all divisions. At Head Suleimanki, a rotational programme was therefore implemented between the divisions under the responsibility of the Superintendent Engineer, Bahawalnagar Circle. First, second and third preferences were allotted to each of the three divisions in 10-day rotation periods, similar to the already ongoing programme of rotations between subdivisions.

The Chishtian Subdivision generally faces a severe water shortage when it is in the third preference. It is left to the discretion of the SDO to distribute the water as equitable as possible. A rotation within the subdivision is, therefore, implemented as the water supply to the tertiary units cannot be regulated. This informal programme is effected between 3 sections of the main canal, i.e., Takhat Mal (RD 245–281), Chak Abdullah (RD 282–316), and Chishtian (RD 316–371) with their offtaking distributaries. Execution of this rotation, which is not documented, is subject to the judgment of the SDO and subordinate regulating staff, who take into consideration the amount of water certain distributaries have received so far during the season in comparison with other distributaries in the subdivision.

Execution of operational orders issued by the canal officers (XEN, SDO) is carried out by gauge readers, who also inform these officers of the water levels, discharges and tail-gauge readings on a daily basis. In the Fordwah Branch, a gauge reader is generally made responsible for the operation of a cross-regulator and one to three secondary intakes just upstream of the regulator.

PERFORMANCE OF THE FORDWAH BRANCH — RESULTS AND DISCUSSION

A first step in the analysis of the performance of an irrigation system in an attempt to identify bottlenecks that affect the performance adversely is to quantify water delivery to different parts of

the system. Following Molden and Gates (1990), a number of performance parameters were calculated for the 14 secondary canals in Chishtian Subdivision. Three performance parameters were calculated: adequacy, dependability and equity. During analysis, a question that arose was how the performance of Fordwah Branch compared with that of canals that have been reported on in previous IIMI-Pakistan research. Much of the research work reported so far was carried out in the command area of Upper and Lower Gugera Branches of Lower Chenab Circle East, Mananwala and Lagar Distributary in the upper reaches, and Khikhi and Pir Mahal in the lower reach of the system. The parameter used in these studies to indicate the degree of (in)equity of the system at secondary level is the amount of water delivered as a fraction of the design discharge. Therefore, a comparison was attempted with the data of the Upper and Lower Gugera distributaries reported earlier (Bhutta 1990, Bhutta et al. 1991).

Adequacy

Generally, a fundamental objective of irrigation systems is to deliver the amount of water required to adequately irrigate crops. However, this was never the stated objective of irrigation systems in the Indus Basin, where the intention at the time of the design of the systems — for the Fordwah Eastern Sadiqia System, some sixty years ago — was to spread the water equitably among the farmers. It has been argued before that the aim of equity of distribution is no longer attained partly as a result of physical shortcomings of the systems (deferred maintenance, siltation), and partly due to the sociopolitical situation where water (and other resources) is distributed on the basis of power and influence rather than in equitable shares among the users. A comparison of the degree of adequacy of the delivered amount among distributaries within a system, and between sets of distributaries in different systems allows a ranking of system performance in terms of adequacy of delivery.

The amount of water required is a function of the area of land that is cropped and irrigated, the crop water requirements of the crops grown on the land, application losses, and cultural practices such as irrigation for land preparation and leaching. Adequacy of delivery depends on water supply, specified delivery schedules, the capacity of the hydraulic structures to deliver irrigation water according to the schedules and the operation and maintenance of the delivery system.

Cropping intensities in the Fordwah Division, originally designed to be 70–80 percent annually, have gone up to 108 percent,⁴ affecting the adequacy of canal water supplies.

Considering the relative service areas of perennial and non-perennial distributaries, and the actual recorded cropping intensities in the command areas of the sample watercourses, the value of the cropping intensity for the command areas of perennial and non-perennial distributaries was taken as 67 percent for the calculation of crop water requirements for kharif 1992. Actual crop water requirements were calculated from the relative areas planted with the main kharif crops, i.e., cotton, rice, sugarcane, fodder and an oil crop (sarson), making use of the FAO program, CROPWAT. Conveyance efficiency was assumed to be 60 percent and no allowance was made for leaching (Van Essen and Van der Feltz 1992).

⁴ According to official ID (Khasra) data (average for 10 years). IIMI data suggest even higher values, with sample watercourses attaining cropping intensities of 150 percent (Kuper and Strosser 1992).

The performance parameter for adequacy, according to Molden and Gates (1990), is :

$$P_A = \frac{1}{T} \sum_T \left(\frac{1}{R} \sum_R \frac{Q_D}{Q_R} \right)$$

where Q_D/Q_R is the ratio of water supply over water demand.

The equation indicates that the values of Q_D and Q_R are defined for discrete locations where water is delivered within the region R , and for finite times within the period T . Ratios of weekly averages of daily values of Q_D and Q_R were calculated and used in the above equation. The performance parameter for adequacy, P_A , for kharif is the arithmetic mean of those ratios for the period of 20 May-12 October. A similar value, P'_A , can be calculated for the ratio Q_D/Q_S , where Q_S stands for the design discharge. As Q_D/Q_S equals the delivery performance ratio, comparison with published values of other systems is possible.

Molden and Gates (1990) present a tentative performance standard in which a P_A value of more than 0.9 is assumed to be good, a value between 0.8 and 0.9 to be fair, and that below 0.8 to be poor.

Dependability

Dependability is defined as uniformity over time of the ratio of the delivered amount, Q_D , to the required amount, Q_R . A system that performs in a consistent manner is considered dependable. The value of this parameter is based on the hypothesis that farmers prefer a system that delivers water in a predictable way, even though it may be inadequate in amount, over a system that is unpredictable but delivers adequately over the entire season. Unpredictability prevents farmers from planning optimal cropping patterns and planting intensities. A farmer can plan for a dependable delivery of an inadequate supply of water by planting less area or growing different crops. Farmers in the Punjab have reacted to the perceived inadequacy/unreliability of canal water supplies by installing large-scale, self-controlled tubewells. Molden and Gates (1990) proposed as a measure of dependability of water delivery the temporal variability in the ratio of Q_D over Q_R , supply over demand. It is expressed as:

$$P_D = \frac{1}{R} \sum_R CV_T \left(\frac{Q_D}{Q_R} \right)$$

where $CV_T(Q_D/Q_R)$ is the temporal coefficient of variation (i.e., the ratio of standard deviation to the mean) of the ratio Q_D/Q_R for one specific location within the region R , over the time period T .

A corresponding value, P'_D , represents the temporal variability in the ratio of Q_D over Q_S .

The closer the value of P_D is to zero, the greater the degree of dependability of water delivery. Molden and Gates (1990) suggest that performance is good if P_D falls between 0 and 0.1, fair for P_D values between 0.11 and 0.2, and poor for P_D values above 0.2.

Equity

Equity of water distribution can be defined as the delivery of a fair share of water to users throughout the system. The fairness of a share may be based on legal rights for water, as in a prior appropriation system, or on the delivery of a fixed proportion of a water supply based on the extent of the irrigated lands served by each outlet. The latter, of course, is done in many rotational schemes, and is the stated objective of water delivery in Pakistan's systems. Molden and Gates (1990) mention that equity of water delivery is a difficult objective to measure because there are many factors that determine the meaning of a "fair share." As was pointed out before in other publications (see e.g., Bandaragoda and Firdousi 1992), fair shares are often interpreted subjectively and have become to depend on the (political) power of the recipient. Measurement of equity of distribution is important as it is used in Pakistan as an indication of the need for management changes required to sustain irrigated agriculture in view of salt accumulation where farmers are irrigating with marginal quality groundwater because of the inequity in the delivery of canal water.

Following Molden and Gates (1990), we define the equity parameter as the spatial uniformity of the ratio of the delivered amount to the required amount (Q_D/Q_R), as in:

$$P_E = \frac{1}{T} \sum_T CV_R \left(\frac{Q_D}{Q_R} \right)$$

$CV_R(Q_D/Q_R)$ is the spatial coefficient of variation of the ratio Q_D/Q_R for a specific time over the region R. This measure describes the degree of variability in relative water delivery from point to point over the region. To assess the equity with reference to the design discharge, a value P'_E is introduced.

The closer the value of P_E is to zero, the greater the degree of equity (spatial uniformity) in delivery. Molden and Gates (1990) suggest as boundaries between good, fair and poor performance in terms of equity, P_E values of 0.1 and 0.2.

Results

Values of the indicators for the secondary canals in the Fordwah Branch downstream of RD 245, calculated as described above, quantify how well the system performs and permit comparison with previously reported results for the Gugera Canal System. The sets of values for the Fordwah Branch and Gugera systems are shown in Table 1.4.

Evidently, the performance of the Fordwah Canal System leaves much to be desired when all three indicators, with respect to the crop water requirements and the design discharges, are rated as "poor." The difference in calculated values between Fordwah and Gugera canal systems is substantial, even though the difference in rating is not. The delivery of water during kharif to Gugera's distributaries is comparatively better, though not significantly, than to Fordwah's, with Gugera rated fair and Fordwah poor. The differences between the two systems are even greater in terms of the variation in discharge delivered to secondary canals, and in the equity of water delivery to these canals, Gugera performing significantly better (at a 5% significance level) than Fordwah. The inflow in both systems is not taken into consideration here. However, available supplies are distributed significantly better (more equitably) in Gugera than in Fordwah, as evidenced by the equity parameter.

Table 1.4. Performance Indicators for Fordwah and Gugera Canal systems during kharif.

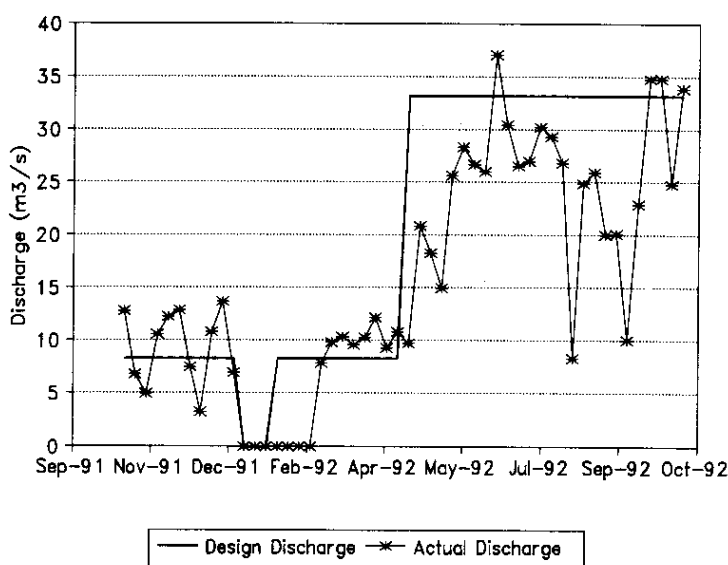
Indicators	Fordwah Branch	Rating	Gugera Branch	Rating
Adequacy (PA)	0.67	Poor		
DPR (P'A)	0.76	Poor	0.81	Fair
Dependability (PD)	0.47	Poor		
Temporal CV (P'D)	0.41	Poor	0.24	Poor
Equity (PE)	0.63	Poor		
Spatial CV (P'E)	0.56	Poor	0.38	Poor

Canal Operations

What are the causes of the poor performance of distributary canals in the Chishtian Subdivision? Performance of the canal system in this subdivision, which forms the lower part of the Fordwah Branch, while being affected by operations/regulations in the subdivision itself, is governed to a large extent by the amount of water that flows into the subsystem, which in turn is a function of the inflow into the Fordwah Canal system and operations/regulations in upstream subdivisions.

The inflow into the subdivision was evaluated at RD 245, upstream of the cross-regulator, where the first distributaries are offtaking, and the results are presented in Figure 1.3. In rabi, the peaks and valleys are a result of the rotation in Eastern Sadiqia Division in which the Sadiq-Ford feeder also participates. The annual closure was prolonged in 1992 from the originally envisaged three weeks to a period of seven weeks, partly due to a unusually heavy desiltation campaign.

Figure 1.3. Inflow in the Chishtian Subdivision at RD 245 (weekly averages, 1991/1992).



Supplies at the start of the kharif season (April to the beginning of June) were well below design, due mainly to a shortage in the supply to the Fordwah Canal. Ten-year averages of water supply to the Fordwah Branch (data provided by the Irrigation Department) show an average deficit in supply of 77 percent and 27 percent for April and May respectively, whereas for June, the situation improves markedly with a deficit of only 8 percent compared to design. The shortage in supply occurs before the rainy season when water levels in the River Chenab, the main source of irrigation water for the Fordwah system during kharif, are low.

Supplies improved during June and this level was fairly well sustained throughout August, September and October. Two steep valleys can be discerned in Figure 1.3 during this period, showing disturbances in the supplies to the subdivision and having an adverse effect on system performance. The first valley, which occurred in the last week of July, was caused by a temporary closure of the link canal feeding the Suleimanki Headworks, forcing the Fordwah System to close for four days. The second valley, which took place in the first week of September, was due to floods in the River Sutlej combined with heavy rains in the Fordwah Division, resulting in the closure of Fordwah Canal for five days. Observations made during 1991 suggest that these types of events occur frequently.

An analysis of the performance of the canal system in the subdivision itself can be made by comparing the three sections between which an informal rotation exists. In Table 1.5, the results are summarized. The calculated values indicate a marked difference in performance between the three sections. P'_A , an indicator of the total volume of water delivered, is rapidly decreasing towards the tail of the Fordwah Branch from a level of 0.79, almost a fair performance according to Molden and Gates (1990), to 0.45 in the tail section. The variation in discharge (P'_D values) does not change towards the tail, indicating that even though the volume of water may be inadequate in the tail section, the delivery of water is no more variable than in the head reach. The distribution of water between the distributaries, however, appears to be worse in the tail section than in the two upstream sections (*vide* the values under the heading "Equity" in the Table).

Table 1.5. Performance of sections of Chishtian Subdivision during kharif 1992.

Section	Equity (P'_E)	Dependability (P'_D)	Adequacy (P'_A)
Takhat Mal	0.52	0.26	0.79
Chak Abdullah	0.46	0.26	0.57
Chishtian	0.65	0.25	0.45

When comparing perennial and non-perennial canals, which officially receive equal shares of water in kharif, it appears that non-perennial canals receive a relatively larger amount of water (at a 5% significance level), with P'_A of 0.75 for non-perennial canals, and a P'_A of 0.52 for perennial canals. In terms of variability, perennial canals are slightly better off, though not significantly so.

Discussion

The inflow into the Chishtian Subdivision, which was found to be both inadequate and unreliable, affects the performance of the canal system in this subdivision. However, the performance deteriorates towards the tail of the subdivision, implying a negative effect of operations in the Chishtian Subdivision on the performance of the 14 secondary canals.

Three rotations coexist at different levels of the system with the rotation at subdivision level being informal and based on the judgment of the SDO or operating staff. While this may be hardly ideal in terms of transparency, both for the implementing personnel and for the beneficiaries, the situation is further aggravated by a series of contradicting operational objectives and system restrictions with different actors across the canal system.

While, officially, all secondary canals should receive an equal share of water during kharif, different actors have different operational preferences. The argument of good quality groundwater is used when commenting on the apparent poor delivery to Azim and the argument of waterlogging is used when indicating a preference for the Fordwah Distributary as compared to Azim.

Gauge readers have been found to give preference to the distributaries offtaking at their own control points and thus reduce the share that is passed on to downstream sections of Fordwah Branch. During interviews, all nine gauge readers in the study area expressed priority for keeping the supply to offtaking distributaries constant at an adequate supply level (keeping in mind the indent) when water levels upstream of their control point in the Fordwah Branch were changing.

Changes in water levels (and discharges) in Fordwah Branch are substantial, with discharges downstream of RD 245 fluctuating more than $3 \text{ m}^3/\text{s}$ (more than 10%) within a day (van Essen and van der Feltz 1992). IIMI's automatic stage recorders indicate that fluctuations in discharge are more pronounced during rabi. This is confirmed by gauge readers who indicate that days with large fluctuations in discharge generally occur two and four days out of seven for kharif and rabi, respectively. Gauge readers responsible for smaller distributaries reported that they would keep their distributaries fully open even when the discharge in the main branch would drop substantially below normal supply level. An explanation for this is that farmers from offtaking distributaries exert more pressure on gauge readers than that by farmers in downstream command areas. When checking the performance of smaller distributaries in comparison to larger ones (with the dividing point arbitrarily taken at $2 \text{ m}^3/\text{s}$), it appears that the average volume of water delivered to small distributaries is significantly better (at a 5% significance level) with $P'A$ equal to 0.74, when the $P'A$ for larger distributaries is 0.54. In terms of dependability, both groups have approximately the same value with 0.44 and 0.48 for large and smaller distributaries, respectively (difference is not significant).

Gauge readers appear to be quite independent in the operation of structures under their control, as is shown by the fact that the number of adjustments in gate settings (resulting in changes in discharge) far exceeds the number of instructions from canal officers (a ratio of about 25:1). This makes the operational preference of gauge readers an important issue in the distribution of water.

When comparing the number of operational instructions from SDO/XEN (Table 1.6), it appears that the attention is focused on RD 199 (handover point for the Chishtian Subdivision) and RD 316. An explanation for the attention to RD 316 could be that it is the only control point in the subdivision with a telegraph that is in working order, other control points relying on messages being taken by *baildars* (Irrigation Department labourers), etc. Similarly, it appears that control points are very rarely visited by (sub)divisional officers, whereas the high number of visits to RD 199 again attract attention.

In contrast, we have the cross-regulator at RD 354 about which little or nothing is heard, which is rarely visited by canal officers, and from where even gauge readings are not relayed anymore. The presence of only one very small distributary upstream of this structure may be an explanation for the apparent lack of interest in this control point.

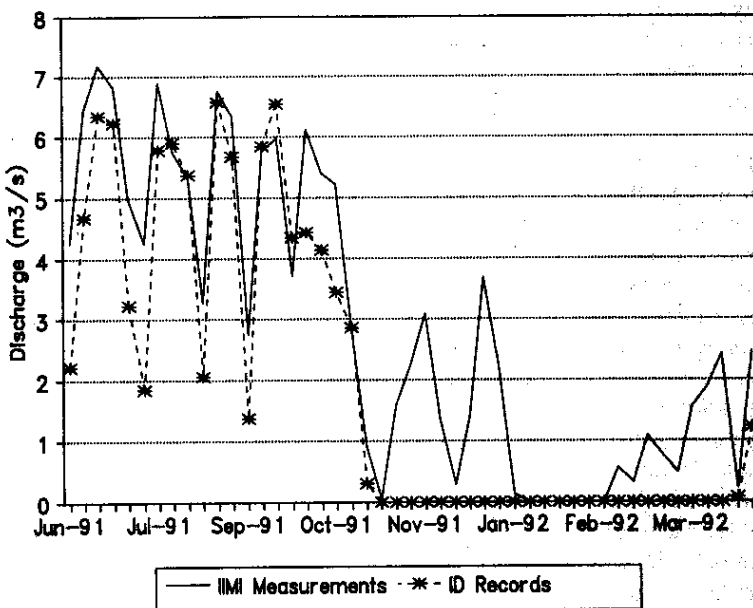
Another cause for the confusion of operating staff is the (non)perenniality of distributaries. Although officially entitled to three allocations of water per rabi season (Siddiqi 1991), when the water supply permits, operating staff are generally under the impression that non-perennial canals are not to be operated. When they are operated, as frequently occurs, personnel often consider this as illegal and records indicate no discharge (see Figure 1.4).

Table 1.6. Operational practices of gauge readers in the Fordwah Branch.

Location	Number and type of structure	Operational orders received per month	Visits (of SDO) per month	Manipulations per day
RD 199	CR, Ds (3)	12	10	0- 5
RD 245	CR, Ds (3)	2	2	2-10
RD 267	Ds (1)	1	1	0- 3
RD 281	CR, Ds (2)	1	1	4-10
RD 297	Ds (1)	3	1	0- 5
RD 316	CR, Ds (2)	15	2	10-15
RD 334	Ds (1)	2	1	0-10
RD 354	CR, (1)	1	0	6-10
RD 371	Ds (3)	4	1	12-20

Notes: CR = cross-regulator
D = distributary

Figure 1.4. IIMI and ID discharges in Azim Distributary — a comparison.



At a number of the smaller distributaries, temporary gauge readers or even (regulation) *baidars* are appointed to monitor the gauges and to adjust the gates. Their experience/training and formal education is generally of a lower level than that of the gauge readers at the more important

control points. Usually, the operating staff at smaller distributaries have no concepts of Full Supply Levels (FSL), discharges or rating tables. In most cases, they do not even report the gauge readings to the gauge readers at the main control points, who are supposed to relay the data to the SDO through the signaller. But these, usually experienced, gauge readers estimate the gauges of the smaller distributaries without having seen them, and convey this data accordingly. The same practice exists at the tail gauges. When such a gauge reader makes a mistake by sending, for instance, a value of 0.3 m (1.0 foot) for a distributary that is officially closed, the signaller intimates to the concerned gauge reader that the tail gauge reading should be zero, upon which this is entered into the gauge register at the site.

Some physical constraints also affect the operation of the system. The flexibility to deal with sudden increases in water levels or discharges in the Chishtian Subdivision, as a result of operations in an upstream subdivision, has been impeded after the existing escape at the very tail of Fordwah Branch ceased to function. This escape, originally intended as a feeder channel for the Bahawal Canal, but used in later years as an escape, has been encroached upon as the frequency with which water was passed through this feeder decreased. Since 1986, it is no longer functional as an escape and irrigation officials therefore deem it undesirable to supply the tail of Fordwah Branch to its FSL. To cope with unexpected rises in water levels in the tail due to upstream operations, an extra safety margin is imposed by supplying less than the design discharge to the tail, and by rotating supplies between Fordwah and Azim Distributary. However, these sudden rises have not been completely eliminated. During kharif 1992, a total number of 22 breaches were observed in distributaries of Chishtian Subdivision, all occurring at times when water levels in these secondary canals were exceptionally high. Out of this total number of breaches, 16 occurred in distributaries in the tail section of the subdivision, indicating that not only water shortfalls are unevenly distributed in the subdivision, as argued previously, but that excesses in supply are also passed down the system. During rabi, these problems are less severe when the non-perennial canals are used to drain excess water.

Finally, an inventory showed that out of 14 distributaries, 8 did not have a rating table for the head structures, whereas 6 did have one, rendering the estimation of the discharge upon which the kacha rotation in the subdivision is based even more questionable. The existing rating tables for 6 distributaries are generally more than ten-years old. Hydraulic conditions of structures have changed over time, with siltation in the Fordwah Branch amounting to 0.2 to 1.5 m when comparing design and actual bed levels (van Essen and van der Feltz 1992). As a result, a number of structures in the canal system are operated under different (submerged) hydraulic conditions than envisaged in the rating tables.

CANAL PERFORMANCE AT SECONDARY AND TERTIARY LEVELS

Flow measurements were carried out on a routine basis by IIMI field staff at the distributary outlets (moghas) of 8 sample watercourses, 4 offtaking from the Azim and 4 from the Fordwah Distributary. In addition, tail gauges in both distributaries were observed daily, providing an opportunity to study the impact of main system performance on the distribution of water at lower levels of the system. The delivery of water to the secondary canals differs substantially in terms of adequacy and dependability, with Fordwah performing better than Azim Distributary (see Table 1.7).⁵

⁵ A high degree of performance is associated with high values of the adequacy parameter and low values of the dependability parameter (temporal variability in water delivery).

Table 1.7. Water delivery to Fordwah and Azim distributaries during kharif 1992.

Distributary	Dependability (P'D)	Adequacy (P'A)
Azim	0.66	0.39
Fordwah	0.37	0.57
Average of Chishtian Subdivision	0.41	0.76

The measurements of water supply to 4 sample watercourses, expressed as millimeters (mm) of water supplied to the service areas of the watercourses, are presented in Table 1.8. The same Table presents data of the amounts of water, in mm, derived by pumping from groundwater, and from rainfall. The total amounts of water received are also given in the Table as relative water supplies (ratio of amount supplied to that required, according to the calculated crop water needs).

It is clear from the figures presented in Table 1.8 that tubewells are an important source of water, and more so when the canal water supply is perceived to be inadequate and unreliable (Azim 111). Utilization of groundwater enables farmers to adequately meet crop water requirements for a cropping intensity that is much higher than originally envisaged, and provides farmers with an opportunity for flexibility in their irrigation application (Kuper and Strosser 1992).

The existence of highly active water trading is further evidence of farmers' need for flexibility in the supply of irrigation water. It was found that farmers purchase or exchange parts, or even entire canal turns, as well as tubewell water (Kuper and Strosser 1992). Sixty farmers who were interviewed in the command areas of the sample watercourses all said that they participated in transactions of water.

The two kharif seasons differed substantially in the amount of rainfall received; the rainfall during kharif 1992 was 3 times that during kharif 1991. Canal supplies were also more for two watercourse command areas, Fordwah 130 and Azim 111. During the annual closure of 1992, the sill level of the orifice structure (the *moghas* are all adjustable proportional modules) of Fordwah 62 was raised by 12 cm (0.4 foot), reducing the actual discharge. Although the dimensions of the structure were restored to what they were before the annual closure, the total amount of canal water received in the watercourse command area during kharif 1992 was about 18 percent less than what was received the year before. Also, during the annual closure of 1992, the sill of the mogha of Fordwah 130 was lowered by 12 cm thus increasing the design discharge, which is apparent from the increased canal supply (20% more than the year before).

Table 1.8. Sources of irrigation water and Relative Water Supply (RWS) for sample watercourses during kharif.

Watercourse	Canal (mm)		Tubewell (mm)		Rainfall (mm)		RWS	
	1991	1992	1991	1992	1991	1992	1991	1992
Azim 63	295	256	377	248	50	165	0.82	0.91
Azim 111	77	120	658	671	47	88	0.73	1.05
Fordwah 62	522	413	126	78	44	121	0.73	0.74
Fordwah 130	387	482	318	165	42	127	0.76	0.93

The changes in canal supplies for the two watercourses offtaking from Azim reflect the effect of the substantial desiltation that took place in these and many other distributaries during the annual closure of 1992. The watercourses in head reach and middle reach receive less water after the cleaning of the canal while the tail watercourses, such as Azim 111, receive more than they did earlier.

Pumping of groundwater in three of the four command areas was markedly less in kharif 1992 than in kharif 1991, showing that farmers reacted (in the management of their tubewells) to the higher rainfall in the area during 1992 (and to a higher canal supply as in the case of Fordwah 130). The reaction to rainfall is even more apparent when monthly figures, rather than the seasonal figures of Table 1.8, are compared. An arbitrary example is given by the data for Azim 63, where the tubewell water supply was 56 mm in June 1992 when there was no rainfall, and 9 mm in July when rainfall was 67 mm, while canal supplies were the same in both months and crop water requirements were similar for both months. As cotton is the main crop in the command area, it shows good water management when farmers reduce the supplies during rains.

The smallest change in groundwater extraction occurred in Azim 111, where tubewell pumpage actually increased by a small amount. Total water supplies for the command area of this watercourse increased by 28 percent resulting in a rise in relative water supply to a value in excess of 1. The situation was confounded by a decrease in crop water requirements of about 11 percent due to a decrease in area irrigated in 1992 compared to that for 1991.

Total water supplies in 1992 were also more than that for 1991 in Fordwah 130 (11%), and (by a smaller amount) in Fordwah 62 (3%). The corresponding values of the relative water supplies increased accordingly. The increase in RWS in Azim 63 is due to a decrease in irrigated area (11%) rather than to an increase in total supply of water received, which remained the same for this watercourse command.

The extent of equity of distribution and dependability of water delivery (that were identified in an earlier paragraph) at main and secondary levels were also evaluated at tertiary level from the discharge values at the outlets (moghas) of the eight sample watercourses. Weekly average discharges, which IIMI field staff calculated from head readings of the calibrated moghas as fractions of the design discharge of the mogha formed the basis of the evaluation. The temporal coefficients of variability of these weekly averages over the kharif season of 1992 are listed in Table 1.9.

Table 1.9. Performance indicators for water intake of sample watercourses in kharif 1992.

Watercourse	Adequacy (P'A)	Dependability (P'D)	Watercourse	Adequacy (P'A)	Dependability (P'D)
Azim 20	1.08	0.40	Fordwah 14	0.98	0.41
Azim 43	0.77	0.51	Fordwah 46	1.17	0.34
Azim 63	0.50	0.55	Fordwah 62	1.27	0.31
Azim 111	0.29	0.74	Fordwah 130	0.79	0.42

The values of these coefficients of variability give an indication of the dependability of water delivery at the heads of the sample watercourses. Dependability of supply at these distributary outlets is poor, according to the performance classes suggested by Molden and Gates (1990) and, not surprisingly, becomes poorer down the distributary, particularly in the case of Azim.

Equity of water delivery, at watercourse level, down the distributaries was also calculated from the weekly average discharges. The average spatial coefficient of variation of delivered flow

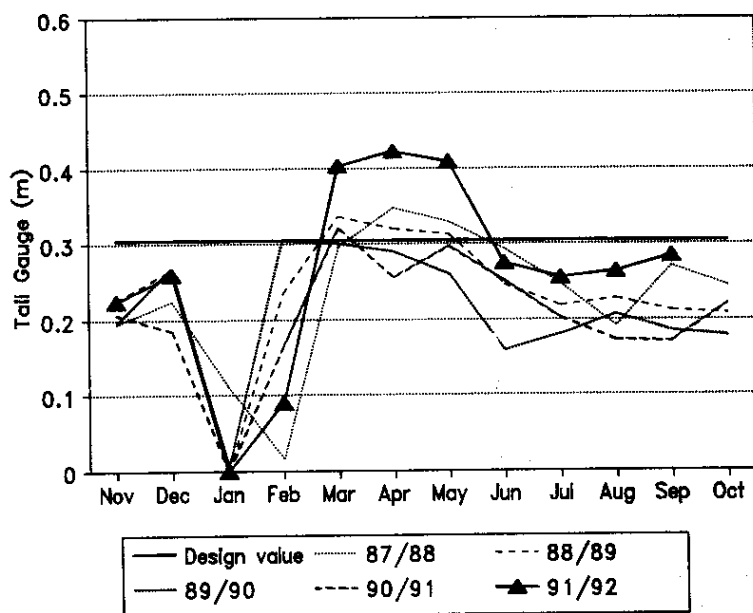
over design discharge for kharif 1992 was 0.23 for the four watercourses offtaking from Fordwah Distributary, and 0.62 for those offtaking from Azim. Performance in terms of equity at tertiary level is obviously not very good in both cases, but considerably worse for Azim than for Fordwah (see also the calculated values for P^*A). Using the criteria of Molden and Gates (1990) once again, the value for Fordwah would be classified as fair.

The performance of both distributaries appears to have improved in kharif 1992, compared with kharif 1991 as evidenced by Table 1.10, where values of performance parameters are given for the two seasons, i.e., the amounts of water delivered (adequacy), and the temporal variability (dependability parameter).

Table 1.10. Performance of four sample watercourses in Azim and Fordwah distributaries — a comparison between kharif 1991 and kharif 1992.

Watercourse	Adequacy		Dependability	
	1991	1992	1991	1992
Azim 63 L	0.58	0.50	0.39	0.55
Azim 111 L	0.17	0.29	0.96	0.64
Fordwah 62 R	1.46	1.21	0.17	0.33
Fordwah 130 R	0.61	0.79	0.52	0.43

Figure 1.5. Tail-gauge readings of Fordwah Distributary (1987–92).



The difference between the parameter values of head-reach and tail-reach watercourses is smaller in 1992 than in 1991. In large measure, this is due to the desiltation and mogha remodeling that were carried out during the annual closure of 1992, as was mentioned before.

Monitoring of the water level at a tail gauge of the distributary provides an indication of whether equity of distribution has been attained within the distributary or not. According to the design, the water level at the tail gauge should be 0.3 m to have equitable conditions along the distributary. Taking Fordwah as an example (Figure 1.5), it is clear that the tail conditions have improved substantially in 1992, although the discharge at the head of the distributary was lower in 1992 than in 1991.

Towards the latter part of the kharif, tail-gauge levels tended to come down to the levels of previous years. This may be attributed in part to siltation occurring during kharif when silt loads are high, but the fact that, under pressure from farmers, the recently remodeled moghas in the head reach were again brought back to the size they had before the remodeling has certainly contributed to the reduction in tail water levels, and hence to reduced equity of distribution. For example, 22 percent of the remodeled outlets of Fordwah Distributary were reverted to the original size, compared to only 10 percent in Azim. The lower degree of cooperation and organization among farmers in the Azim command area (Van Waaijen 1991), mentioned earlier, may have played a role here.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the analysis of flow data and current operational practices in the Fordwah System, as discussed in this paper, a set of practical recommendations are discussed below. It would not be difficult to suggest more and more far-reaching changes, but the authors feel that implementation of this initial set would test the desire of Irrigation Department staff to improve and sustain irrigation in the area. Monitoring of the effects of implementing this set of recommendations would provide the bench mark against which further, and probably more expensive, management changes and technical improvements, including the expected impact of the construction of surface and/or subsurface drainage systems in the area, could be measured. The authors feel that it would be irrational to suggest now that lining of canals or the construction of drainage systems is required to sustain irrigated agriculture in the area. Once this set of recommendations has been implemented and their effects monitored, other technological and managerial improvements could be considered.

1. Presently, the quality of the daily readings that are relayed from the control structures to the office of the (sub)system manager leaves much to be desired. Tail gauges and water levels at the head of smaller distributaries are fictitious and gauge readings are generally reported in such a way that they are in agreement with the official policy rather than reflecting the actual situation in the system. This is mainly caused by the fact that these data, considered to be of vital importance at the time of design and at earlier stages of operation, are no longer used by the system managers to make decisions on operation and maintenance of the system. The system manager is not confronted with the consequences of operational decisions on the water distribution other than through remonstrations of farmers. It is recommended that IIMI starts collaborating with the Punjab Irrigation Department in a pilot activity to emphasize the importance of information in an irrigation system and to quantify the impact of operational decisions on the distribution of canal water supplies.

2. Three different rotations occurring simultaneously at different levels of the irrigation system, coupled with a number of individually conceived operational rules that are followed within the system make it difficult — if not impossible — to assess the actual discharges in comparison to the intended discharges at any given point in the system. Visualizing of irrigation operations in the Fordwah Division by displaying actual and intended water levels and discharges in the office of the system manager is recommended. This should aim at making the process of water allocation and actual distribution of water more transparent both for operators and end-users.
3. The performance assessment carried out in this study clearly indicates that present operational objectives are not attained and that there is certainly scope for improvement, when all performance indicators with respect to the design discharges are rated as "poor." It is recommended that the information generated by such assessments be made available to the system manager on a regular basis through a set of institutionalized indicators that would quantify irrigation operations in a straightforward, comprehensible way.
4. Operating staff, such as gauge readers, have been observed to adjust the gates of their control structures frequently without any instructions to that effect, and with limited (localized) objectives as, for example, to keep the discharge in an offtaking distributary canal constant. Through these frequent interferences in the system, gauge readers exert a substantial influence on the performance of the system. These interferences take place in the absence of a clear operational plan and in a situation where operational guidelines are not available. It is recommended that a study be carried out on the impact of gauge readers' operations on system performance through mathematical modeling. The objective of the study would be to derive a comprehensive decision-tree for all levels of the system, and to identify the minimum information required to make rational decisions at the various levels.
5. More than half of the secondary canals in the Chishtian Subdivision do not have rating tables for their head structures, whereas the tables for the other distributaries have been established more than 10 years ago and have never been revised. Quantification of the flow of water in the subdivision has therefore become nearly impossible with any acceptable degree of precision. It is recommended that the ID should recalibrate all head structures in due time, and set priorities for this activity based on an assessment of control points which need recalibration most.
6. Farmers reportedly exert pressure on operating staff, either directly or through influential people, to gain operational advantages. It is recommended that the ID should recognize the presence of this phenomenon and start making use of the informally organized farmers' groups to tackle previously intractable problems such as water theft and distributary maintenance (e.g., desiltation and berm cutting).
7. Formal operational rules dating back to the design of the system and informal operational practices have led to a rigid supply-based operation of the system. The flexibility that farmers require in the management of their irrigation applications in order to respond to changes in crop water requirements over a season has led them to develop tubewells even in areas where groundwater is at best marginally suitable for irrigation. Flexibility in water supplies is also enhanced by the trading of canal and tubewell water between farmers. It is recommended that the ID should take cognizance of these developments and attempt to maximize the benefits of the groundwater resource for farmers by adjusting canal supplies in a way that would stimulate the development of successful patterns of

conjunctive management of surface water and groundwater wherever that is possible. In the allocation of canal supplies between rotating distributaries, the ID staff have to take into account the effects of their decisions on the average irrigation water quality over time that results from using canal and tubewell water in each command area.

8. Relative water supplies are maintained around 0.8-0.9 by *de facto* conjunctive management of groundwater by farmers to suit the availability of canal supplies and rainfall, which goes to show that farmers operate the only source presently under their control in such a way that water is applied near optimally in an economic sense. The inbuilt danger of these irrigation practices is the emergence of salinity, even in areas where water tables are low, through under-irrigation and the absence of leaching practices of farmers. It is recommended that further research be carried out to ascertain current field irrigation practices of farmers, with a view to evaluating the (potential) role of the surface irrigation system in managing problems of waterlogging and salinity to avoid land degradation and to mitigate the effects on agricultural production.

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CHAPTER 2

Achieving Cost-Effective Rehabilitation and Modernization of Irrigation Systems: Research Results from Sri Lanka

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REHABILITATION AND MODERNIZATION

THE WATER DELIVERY performance of every irrigation system deteriorates over time. Rehabilitation and modernization (R&M) projects are aimed at arresting or reversing this process. Rehabilitation of an irrigation system refers to restoring the capacity lost over time. Modernization of an irrigation system refers to changing the existing design to make it cater to new demands or to incorporate new technologies to make it more efficient. It is now generally accepted that rehabilitation and modernization (R&M) should be undertaken at the same time. One basic element in all R&M projects is that the water conveyance and distribution system is improved; however, an R&M project is distinguished from maintenance in that the R&M project focuses on the whole system at once.

R&M projects have been a major form of investment in irrigation for more than 20 years. Over that time, a great deal has been learned about how to make such projects effective. A key unanswered issue is how to ensure that an R&M project is *cost-effective*. This paper uses data on projects for the R&M of major irrigation systems in Sri Lanka in an attempt to answer that question. As will be shown, the answer lies in the process through which R&M projects are planned, implemented, and managed.

REHABILITATION AND MODERNIZATION OF IRRIGATION SYSTEMS IN SRI LANKA

Irrigation in Sri Lanka

Irrigation is extremely important for agriculture in Sri Lanka; almost all rice — the staple food — is produced on irrigated land. Sri Lankans classify irrigation systems into “major systems” with command areas greater than 80 hectares, and “minor systems” with command areas of 80 hectares or less. Over two thirds of Sri Lanka’s irrigated land is under major systems. Major systems are managed by government agencies while minor systems are managed directly by farmers.

In Sri Lanka, construction of new irrigation systems has largely ended. The best locations have already been developed and the costs of construction of new systems have risen sharply while the value of the major product — rice — has declined (Aluwihare and Kikuchi 1991). Therefore,

the Government of Sri Lanka has adopted a policy of investing in the rehabilitation and modernization (R&M) of existing irrigation systems (IMPISA 1992). Since 1975, investments in R&M have grown while those in new construction have declined.

Although R&M of minor systems continue to remain an important component of public and private investment in agriculture, this paper concentrates solely on R&M of major systems. The lessons learned from R&M of major systems, while applicable to minor systems, will need to be reformulated to fit the different management organizations of minor systems.

R&M Projects in Sri Lanka

R&M of major systems have been undertaken primarily through large-scale projects partially funded by foreign donors. There have been five such projects:

1. Tank Irrigation Modernization Project (TIMP): 1976–1983
2. Water Management Project at Gal Oya (WMP): 1979–1985
3. Walawe Irrigation Improvement Project (WIIP): 1985–1993
4. Major Irrigation Rehabilitation Project (MIRP): 1985–1993
5. Irrigation Systems Management Project (ISMP): 1987–1992

Altogether these projects have undertaken R&M work on 18 major irrigation systems. The total cost of these projects have ranged from US\$18 million (WMP) to over US\$30 million (MIRP). Most of the funding has been provided by foreign donors. WMP and ISMP were largely funded by USAID loans and grants, TIMP and MIRP were partially funded by World Bank loans, and the WIIP was mostly funded by loans from the Asian Development Bank.

Data on these five projects form the basis for the analysis in this paper and they have been drawn primarily from the following sources:

1. A literature review commissioned by IIMI under its agreement with USAID to manage the research component of ISMP; this study covered all five of the projects and was prepared by Dr. W.A.T. Abeysekera (Abeysekera 1992).
2. A field study and analysis of four of the five projects also commissioned by IIMI under its agreement to manage the research component of ISMP; this study covered four projects — TIMP, WMP, MIRP, and ISMP — and was undertaken by a team from Engineering Consultants Ltd. and Associated Development Research Consultants (ECL/ADRC 1992).
3. IIMI studies of WIIP under its agreement with the Asian Development Bank to provide assistance to the project (IIMI 1990; Nijman 1991).

Two of the projects, TIMP and WMP, have been studied in great detail and have an extensive literature.

This paper and much of the data are the products of the research component of the Irrigation Systems Management Project (ISMP). One goal of ISMP was contributing to knowledge about how to achieve cost-effective R&M. ISMP itself was originally designed to contribute to

knowledge about R&M processes by providing different levels of funding for construction in different irrigation systems for comparison of cost-effectiveness. During implementation, the design was changed so that the original comparison could not be used. However, the ISMP research component has included studies of several aspects of R&M, including farmer participation and the use of existing structures for flow measurements, as well as the studies on which this paper is based. Also, the implications of the various ISMP studies for the conduct of R&M projects were discussed by top-level Sri Lankan irrigation professionals at a national workshop organized by IIMI in June 1992. The workshop resulted in a set of guidelines for future Sri Lankan R&M projects to be published shortly by IIMI.

THE FINDINGS ON REHABILITATION AND MODERNIZATION PROJECTS

Evaluation of the Sample Projects

This analysis compares various aspects of the five projects to determine which features help ensure cost-effectiveness. For purposes of analysis, the five R&M projects are categorized on the basis of cost-effectiveness using traditional economic analysis.

Table 2.1 gives estimates of the benefit/cost ratios and internal rates of return (IRR) for the five projects. These figures are not definitive. The data needed to conclusively judge the economic soundness of these projects, three of which are not yet completed, are not available. However, these figures support the following categorization of projects:

1. TIMP was probably not cost-effective. The two systems listed include Mahawilachchiya whose performance is considered excellent by many specialists but whose construction costs were very high. Mahawilachchiya also has good water availability. In the other scheme, Mahakanadarawa, cultivation has failed in most seasons for lack of water. Analysis of the three other systems rehabilitated by TIMP might change the picture but that would probably not change the conclusion.
2. WMP focused on only one system — Gal Oya Left Bank — then the largest system in the country. These figures show that WMP was cost-effective, a conclusion that agrees with the end-of-project evaluation (ISTI 1985).
3. MIRP is an ongoing project rehabilitating four systems; hence, the figures given here cannot be taken as final. However, these figures show that MIRP has had significantly different results under different conditions. In particular, the Huruluwewa Scheme has severe water availability problems while Rajangana, on the other hand, has no shortage of water.
4. As shown by the figures, ISMP is probably a cost-effective project. However, rehabilitation construction on the ISMP systems will continue for some time though the main portion of the project has been completed. The two systems listed here are reasonable representatives of the six systems where ISMP work has been carried out. Analysis of the others would probably not change the conclusion of the authors. The difference between the two schemes can be explained by the greater improvement in equity of distribution in Kaudulla than in Minneriya. Historically, Kaudulla has had greater head-tail problems than Minneriya.

Table 2.1. Economic evaluation of the projects.

Project	Scheme	B/C ratio	IRR
TIMP	Mahawilachchiya	0.56	— ¹
	Mahakanadarawa	0.21	— ¹
MIRP	Rajangana	1.30	16.4%
	Huruluwewa	0.67	— ¹
WMP	Gal Oya Left Bank	1.57	33.0%
ISMP	Kaudulla	2.24	30.0%
	Minneriya	1.29	16.5%
WIIP	Uda Walawe	— ²	8.0%

¹The IRRs for these schemes were negative. ²No B/C ratio calculated.

Notes: B/C ratio = Benefit/Cost ratio.

IRR = Internal rate of return.

Sources: For TIMP, MIRP, WMP, ISMP: ECL/ADRC 1992
FOR WIIP: IIMI 1990

5. WIIP is still underway but it will probably not be cost-effective, in large part because the work done and planned will not bring any significant additional area under cultivation. Unlike the other figures, the IRR figure shown for WIIP is not a current estimate but one made by IIMI in 1990.

Based on this evidence, WMP and ISMP are categorized as cost-effective, TIMP and WIIP as not cost-effective, and MIRP as unsure. The following subsections explain some reasons for these results.

R&M Project Components

Balance between hardware and software

A key finding is that the five R&M projects have placed very different emphases on different components. All five of the projects included the following major components:

1. Physical works including earthwork on canals, the rebuilding of concrete and masonry structures, and the building of new structures.
2. Design of a new operations system.
3. Design of a new management structure, sometimes incorporating some farmer involvement (institutional development).

In addition, some projects have included other components some of which are:

1. Agriculture improvements (TIMP, ISMP, MIRP).

2. Roads and other rural infrastructure (TIMP, MIRP, WIIP).
3. Research (ISMP, WMP, WIIP, MIRP).

All of the projects also included training and other support for the major components.

However, the resources allocated to the components have differed significantly among the various projects. Table 2.2 shows an estimated breakdown among major components for the five projects.

Table 2.2. Major cost components of the projects (in percent).

Major component	TIMP	WIIP	MIRP	WMP	ISMP
1. Physical works	67	90	70	63	63
3. Institutional development	0	0	7	18	15
4. Others	32	8	15	6	9
Total	100	100	100	100	100

Note: The authors have found it very difficult to allocate project costs among these various components because accounting has not been done in these components. The figures given in the Table are based on information available on component breakdown and the authors' estimates of efforts put into each component.

Table 2.2 illustrates several important points:

1. Physical irrigation works dominate the budgets of all the projects.
2. The five projects fall into three categories with regard to expenditures on components:
 - TIMP and WIIP put very little resources into the software items, i.e., O&M systems and institutional development.
 - WMP and ISMP put significant funds into the software items.
 - MIRP is intermediate.
3. Only TIMP put a large amount of resources into other activities. TIMP invested a great deal in the purchase and distribution of tractors and other agricultural equipment and inputs to promote a new cropping system. The proposed cropping system turned out to be unacceptable to the farmers for a variety of reasons. As a consequence, none of the later projects has dedicated significant resources to agricultural development. Without this large investment in agricultural development, TIMP's distribution of funds would be similar to that of WIIP.

ISMP and WMP, classified as cost-effective, are the two projects that put the most resources into the software components. TIMP and WIIP, classified as not cost-effective, put the least into the software components. MIRP is intermediate to both categorizations.

Clearly, this finding shows that investment in software components is an essential complement to investment in physical works. The implications are: a) that a balance between software and hardware components is necessary; and b) that WMP and ISMP were closer to the ideal balance than were the other projects.

This finding agrees with other analyses which suggest that investments in operation and maintenance (O&M) and institutional development together with investment in physical works are likely to have a bigger payoff than investment in physical works alone (Aluwihare and Kikuchi 1991). The basic reasons for this conclusion are well-known:

1. R&M are attractive when the performance of a system declines significantly. The decline may be due to (a) increased demands (enlargement of the command, increased cropping intensity, etc.), or (b) deterioration in the physical system that makes effective operations impossible. The former implies a need for improved operations; the latter, a need for improved maintenance. Reconstruction of existing structures and construction of new structures alone without improvement of O&M will not solve the basic problems leading to the need for R&M.
2. Improvement of O&M systems requires significant investments. It is not enough for engineers to work out a new operational plan; the plan must be tried, negotiated with farmers, and modified as needed for the particular scheme. Moreover, the use of new technologies, as implied by modernization, generally means that system operators themselves need training and learning time to make the new O&M systems function well.
3. Inadequate maintenance and poor water distribution generally imply, at least in Sri Lanka, that farmers are not taking sufficient responsibility for management. In some cases, they may interfere with agency plans; in others, agencies lack the funds and trained manpower to handle the maintenance and water distribution needs. In either case, there is a need for the development of institutions among the farmers so that they can effectively and responsibly contribute to overall system management. However, institutional development cannot be accomplished without resources.

Thus while physical works are a key element of an R&M project, the physical works must be supported by investments in O&M systems and institutional development to ensure that needed O&M changes take place.

For example, all of the projects except TIMP have incorporated greater control over water flows by adding measuring and other control structures and have proposed operating plans that require the use of these structures. This approach has been in line with expert opinion from outside Sri Lanka. However, development of the management systems to make use of increased control over water flows has lagged. WIIP simply assumed that the system managers and management systems could make effective use of this control (Nijman 1991). WMP and ISMP, on the other hand, expended a fair amount of resources on improving the management systems and managers' capabilities so that the increased control would be effectively used. Again MIRP has been intermediate.

The failure to provide funding for an item does not mean that the project planners omitted the item. Thus, although no funding was provided by TIMP for institutional development, its plans called for the establishment of Tank Committees with farmer representatives to manage the schemes after R&M. However, it was assumed by the planners that whatever costs there would be would be covered through regular government budgets. Similarly, most of the TIMP funding for agricultural development went for the purchase of tractors; it was assumed that the additional

extension work required to get the farmers to adopt a new cropping schedule as proposed by the project would be met from regular funds. The experience in Sri Lanka is that extra government funding has rarely been made available unless explicitly provided for in the project budget. The lesson is that R&M project budgets must make explicit provision for the key items.

Farmer organizations

Effective management decisions require farmer input. On major systems with thousands of farmers, farmer input is possible only when the farmers are organized. Thus the creation or strengthening of farmer organizations is a key element in institutional development for R&M.

All the projects incorporated the idea of farmer organization and involvement in O&M. TIMP and WIIP assumed that adequate organizations existed and dedicated no resources to creating organizations. WMP, ISMP, and MIRP explicitly made creation of farmer organizations one of the goals, although the resources dedicated to this end under MIRP were, initially, meager. All three projects have had considerable success in creating effective farmer organizations. WMP was the earliest of these and the methods developed for WMP came to serve as models for both of the later projects. A large part of the success of both WMP and ISMP must be attributed to the participation of the farmers through their organizations.

Farmer organizations can provide assistance to the R&M process itself as well as help with O&M after the project. It takes time, however, to create farmer organizations from scratch. Results from WMP suggest that it takes up to two years to create effective farmer organizations. Since the creation of organizations has been part of the R&M projects, this lead time means that farmer organizations could not participate in project planning and initial implementation.

Based on experiences in WMP and others, in 1988, the Government of Sri Lanka adopted a "participatory management" policy for the management of major irrigation systems. This policy calls for the turnover of operating and management responsibilities for the lower levels of major irrigation systems to farmer organizations. To support the policy, the government has created programs to organize farmers in major irrigation schemes. Unfortunately, except where funds from R&M projects have been available, the government has not been able to dedicate adequate resources to achieve fully functioning and effective farmer organizations.

R&M Project Planning

Planning, including selection of systems for R&M work, and selection of the main elements of the project, also differed significantly among the five projects. Three key aspects of planning are considered here: planning studies, selection of technology, and provision for modifications during implementation.

Planning studies

One common trait of all five projects is that basic planning was done early in the project and was based largely on studies by consultants, generally foreign consultants. Three of the projects, TIMP, MIRP, and ISMP, were intended to rehabilitate and modernize multiple schemes; hence, the studies were necessarily superficial. The basic studies for WMP were also superficial. For WIIP, there were multiple studies (IIMI 1990; Nijman 1991) but all were superficial and they came to different conclusions.

These studies do not attempt to justify selection of these particular schemes rather than other schemes. They do attempt to show that R&M of the selected schemes constitute a good investment. Even in the latter type of analysis, the superficiality of the studies, particularly in the area of water availability, has sometimes defeated the purpose of project planning.

The most obvious example is that of Mahakanadarawa, one of the TIMP schemes. This scheme has long had a history of crop failures due to lack of water in the tank. Yet, Mahakanadarawa was selected for TIMP, a project that proposed costly lining in most of the canals. Without water to distribute through the canals, there could be no increased crop production to justify the costs. The water availability problem at Mahakanadarawa was known to many people, including the system operators and the farmers, yet it was dismissed by project planners on the grounds of uncertainty.

The Huruluwewa Scheme, now being rehabilitated by MIRP, has similar but less extreme water availability problems. Here it was assumed that the water availability problems would be solved by the construction of a feeder canal to the reservoir, an activity outside of the R&M project. The poor evaluation of MIRP performance at Huruluwewa (see Table 2.2) is largely due to the water availability problems.

Planning for changes during implementation

Analysis of WMP shows that although the original plans were drawn up by foreign consultants based on inadequate studies, the plans themselves made provision for changes during implementation. For WMP, R&M work was planned on the following basis:

1. One of the two main factors considered responsible for the decline in performance of the scheme (Gal Oya Left Bank) was physical deterioration of the system. Therefore, rehabilitation was intended to bring the scheme back to its original operating capabilities. The scheme was not to be redesigned although some clear errors and problems were to be corrected.
2. The second major factor considered responsible for the situation was that farmers were not adequately performing their channel maintenance and water distribution functions. Based on USAID's experience with the On Farm Water Management Project in Pakistan, it was proposed that farmers would be organized for two purposes: a) to contribute free labor to rehabilitate the field channels; and b) to enable the farmers to maintain field channels and distribute water among themselves more adequately.
3. A Master Plan was to be developed to address various problems of the scheme during implementation of the rehabilitation work. It would incorporate a new operating system. Research work by contractors and outside agencies was planned to help with this effort.
4. Explicit provision, including scheduling an outside midterm evaluation, was made for monitoring and evaluating the progress and impact of the project. These provisions are discussed in detail below.

As shown by the last two items, WMP explicitly incorporated the idea of learning lessons and planning future operations based on those lessons. Major changes were made during implementation of WMP, many of them following a midterm evaluation that suggested some of the changes. The following are some of these changes:

1. The original purpose of rehabilitation was modified. The goal became "pragmatic rehabilitation" whose objectives were installing adequate controls to deliver the water as

planned and ensuring the stability of the system. This was a much cheaper approach since it did not mean reconstructing most of the canals.

2. The goals of the farmer organization program were broadened to include farmer participation in operation and maintenance, in solution of conflicts over water, and in seasonal planning through the organizations. This change occurred as the implementors learned that farmers could take a great deal more responsibility than was originally thought.
3. The Master Plan approach was junked when it was found that it had little to offer. Instead, attention was focused on selecting an operating plan and developing the capabilities of the Irrigation Department officers to implement that or any other plan successfully. For this purpose, a computer-based information system was developed and put into use.

Like WMP, all the projects suffered from inadequate planning studies. They differed considerably in approach to modifications during implementation. The differences can be briefly summarized as follows:

1. TIMP did not explicitly provide resources and opportunities for learning lessons and making changes. Some important changes were made during TIMP implementation because of the extremely high costs of some items.
2. WIIP, like TIMP, did not explicitly provide resources and opportunities for learning lessons and making changes. Few changes have been made during the implementation of WIIP.
3. MIRP made weak provisions for change during implementation. As a result, the major changes that have been made in implementation, such as a great increase in support for farmer organization, have come only late in the project in response to reported success in ISMP.
4. ISMP, like WMP, explicitly provided for learning lessons and making changes. Major changes occurred during implementation, particularly after a midterm evaluation.

Selection of technologies

Selection of technologies for R&M projects is fundamental to planning and this selection has generally been based on current theories of how improvements can be made rather than on detailed local studies of needs. TIMP offers an instructive example. TIMP was based on ideas that were rather radical at the time. The basic elements of the project were:

1. The rehabilitated systems would be redesigned so that most farms would be served from one-cusec canals.
2. These canals would be lined to minimize losses and prevent farmers from tampering with them.
3. Farms would be served through rotations on the field channels.
4. Farmers would adopt a new cropping schedule calling for dry plowing and early sowing to make maximum use of rainfall.

These ideas were drawn from a variety of sources. Both the one-cusec canal and the rotation idea appear to have been derived from the idea, common among irrigation engineers worldwide at the time, that most of the inefficiencies were at the tertiary level. The value of lining was also widely accepted by experts at the time, and the cropping schedule idea was based on experiments carried out on a small scale within Sri Lanka itself. These elements were adopted without extensive consultation with system operators and with no consultation with farmers (Murray-Rust and Rao 1987).

During and after implementation it was found that:

1. The one-cusec canal design within TIMP may be effective in simplifying operations. This seems to be the case in Mahawilachchiya. However, this feature is very expensive because it requires the reconstruction of many canals and the construction of many parallel canals to reduce all field channels to the one-cusec size.
2. Because of its cost, canal lining was controversial. In Mahawilachchiya, the ECL/ADRC team found that the lining was in very good condition ten years after completion of the work and that the system was functioning very well. Lining had reduced maintenance needs although it complicates maintenance activities when needed. Despite this finding, it cannot be considered cost-effective because the cost of the lining was so high. In TIMP itself, only selective lining was used in the later TIMP schemes.
3. The planned rotations were developed by a foreign consultant working largely by himself; these have since been significantly modified, mostly simplified, through experience. The actual enforcement of rotations on field channels has been left to farmers who change the rotations as they see fit.
4. The proposed cropping schedule was not accepted by farmers. Although the plan was agronomically sound, it led to labor problems for farmers. Also, in those systems where water availability was uncertain, farmers felt that it increased their risks unacceptably.

Since TIMP was the first of the projects, some of its lessons were incorporated into subsequent projects. Thus none of the more recent projects have recommended large-scale field-channel or distributary-channel lining and none have adopted a single agricultural plan. The one-cusec canal design and low-level rotations were adopted in WIIP and, partially, in MIRP.

For TIMP, the basic technologies, including both the operating system and the structures for that operating system, were predetermined by the project plans drawn up by experts with no provision for modifications during implementation. The same approach was used for WIIP with equally poor results.

In contrast, as was shown in the section on *Planning for changes during implementation* (p. 32), WMP left the choice of technology largely to the project implementors. WMP also explicitly provided for review of plans to allow for changes. WMP approach has had much greater success than has the approach adopted for TIMP. The WMP approach has been taken for the ISMP and MIRP. This success has largely been due to the greater knowledge the implementors had of individual system needs.

The implication is that choice of technology must be based on detailed knowledge of local needs that can be gained only over time. In turn, this implies that the persons who have extensive experience on the system — the system operators and farmers — should play a major part in selection of technology. A second reason for consulting system operators and farmers is that these are the people who must use the technologies after completion of R&M. If they do not agree with

the selected technologies, they may well misuse or modify the new works and systems to fit their felt needs.

Lessons for planning of R&M

Four major lessons can be drawn from this analysis:

1. Much of the knowledge necessary for success in R&M is knowledge about the individual scheme. Not all of the lessons from one scheme are applicable to another. There is a need to individually tailor R&M plans to individual schemes.
2. Adequate studies of the individual schemes, including good assessments of water availability, are needed for project planning. These studies cannot be entrusted solely to consultants, foreign or otherwise, who can spend only a few weeks on the studies, unless they are supported by strong background work. These studies should pay careful attention to the knowledge and experience of the farmers and operators on the scheme.
3. The most successful projects have made explicit provision for modification during implementation as lessons are learned about the scheme. WMP and ISMP not only included resources for research and planning, but also provided for midterm reviews that justified major changes. These midterm reviews based their findings primarily on the opinions of and information from the personnel implementing the project, including farmers.
4. Selection of technology should not be left solely to outside experts. It is important that system operators and farmers be consulted not only to make use of their detailed local knowledge of the scheme but also to ensure that they are agreeable to making proper use of the newly installed systems following R&M.

R&M Project Implementation

These five projects also offer lessons concerning several aspects of project implementation. Many of these are highly technical and of interest only to work in Sri Lanka. For example, experience has shown that it is more effective to base design water levels on historical water levels than on the original design. These local technical issues will not be discussed here. However, three issues of major importance are discussed: a) the involvement of farmers in design, b) the involvement of farmers in construction, and c) the involvement of system operators in project implementation.

Involvement of farmers in design

Under TIMP and WIIP, the design process explicitly excluded farmers. Design was felt to be a matter solely for the technical personnel (engineers and technical assistants). One result has been poorer performance and complaints and destruction by farmers when the systems did not solve their problems or work as the farmers felt they should.

Farmer involvement in the design of field channels was explicitly provided for in WMP, MIRP, and ISMP. However, there have been problems with achieving effective involvement. One has been time pressure. Meeting farmers to discuss designs takes time, particularly if the farmers want something not envisioned by the engineer. An engineer under pressure to complete designs quickly often feels that he cannot afford the time. In all three projects, engineers learned that when

they did not spend the time to involve farmers, farmers gave greater problems at the time of construction or afterward. Thus, greater efforts were made to involve farmers in design as these projects progressed.

Involvement of farmers in construction

WMP, ISMP, and MIRP made it a goal to involve farmers in construction work. There were several reasons: to lower costs by getting free labor from farmers, to ensure good quality construction because farmers have an interest in quality, to give the farmers experience with and greater knowledge of the system, and to help farmer organizations by providing opportunities to raise funds.

As with design, achieving effective involvement of farmers has taken time. Not only must the farmers have the organizational capability to manage construction work, they must also have the technical knowledge. For the latter, experience shows that support from the agencies is critical to success. Not only must the farmers learn how to carry out construction work, the agency personnel must learn how to provide the necessary technical support. The involvement of farmers in construction work in WMP was not as successful as hoped, largely because of inexperience. There has been greater success in both MIRP and ISMP but the results are too new to be evaluated fully.

TIMP attempted to involve farmers in construction, but only as laborers with no say in how it was conducted. This approach was taken in large part because TIMP did not try to organize farmers. Although not included in WIIP plans, giving contracts to farmer organizations is now the policy of the project because of successes in MIRP and ISMP. However, it is not working well yet, in part because the agency involved has little experience in working with farmers, and in part because the farmer organizations are very new.

Involvement of system operators in project implementation

A clear difference can be seen in the implementation strategies of TIMP and WIIP on the one hand, and those of WMP, MIRP and ISMP, on the other. TIMP made few efforts to ensure interaction between project implementors and operators, although they were separate persons from the same agency. In WIIP, project implementors and operators are from different agencies so there has been very little interaction. In both TIMP and WIIP, there was little opportunity for operators to influence system redesign and other aspects of project implementation.

In contrast, in WMP, MIRP and ISMP, there was a great amount of interaction between project implementors and system operators. Under MIRP and ISMP they have largely been the same persons. In WMP, although implementors and operators were generally different persons from the same agency, explicit efforts were made to ensure interaction. In these three projects, system operators have had significant influences on design and construction. The greater amount of interaction has meant that WMP, ISMP and MIRP could adjust to individual system needs more effectively thus making the projects more effective.

Overall approaches to implementation

TIMP and WIIP projects were very top-down. Technologies were selected by planners and design and construction were carried out with little consultation with system operators and with no consultation with the farmers. This approach had two detrimental effects on these projects:

1. It has been very difficult to incorporate local knowledge held by system operators and farmers into the selection of technology and the designs.
2. It lessened the commitment of both operators and farmers to the project. In the case of farmers, this is expressed through increased numbers of complaints and, sometimes, through damage to or destruction of newly built structures.

In the other three projects, both system operators and farmers were consulted on design and the farmers were explicitly involved in construction. The results were that: a) there are fewer problems with new structures and management systems, and b) both groups are more cooperative.

R&M Project Management

The five projects also offer lessons in project management.

Project scheduling

First, none of the five projects have completed construction as scheduled. TIMP, WMP, and MIRP were all extended to allow for completion. ISMP ended officially after finishing only about two thirds of the construction work. Although it has been extended, WIIP will probably not complete the planned physical works.

The basic problem appears to have been that the construction schedules were very optimistic so that it would appear that the projects would be completed within time limits set by the donors. In every case, factors not considered, such as civil disturbances and others, affected the schedule, often severely.

Nor could projects complete their non-construction components on time. For example, despite extension, WMP never finished farmer organization work. Also, ISMP has not yet completed operating system development. Often, judgement of "completion" of these software components is subjective or is based solely on expenditure of the funds.

One important factor always was that no time was allowed for getting all the persons and agencies to work together. These have generally included officers from the irrigation agencies and various agricultural agencies, consultants, local and national administrators at different levels, and others. Not only was it necessary to spend time and effort getting everyone "on board," but also failure to do so slowed implementation. Beginning in 1989, ISMP began a practice of holding annual workshops to prepare the annual plan for the following year. This practice is said to have helped the various implementors greatly in achieving project targets.

Monitoring and evaluation systems

Although none of the projects have had perfect monitoring and evaluation systems, there were major differences that affected project success.

In all of the projects, construction progress has been monitored with reasonable efficiency through periodic reports from the responsible officers. The progress of other components has also been monitored through the same mechanism, although generally less effectively. Unfortunately, this type of monitoring does not include impacts, nor does it include outsider evaluations of performance, both of which are essential for project evaluation. Thus this approach to monitoring generally fails to help with adaptation of activities to local needs.

The performance of the projects with regard to providing data for learning lessons during and after implementation has differed considerably:

1. TIMP included a baseline study and a less elaborate impact assessment at the end of the study. The results of the baseline study came out too late to be of use in project planning. The impact assessment and other studies have provided lessons for subsequent R&M projects.
2. WMP made explicit plans for outside monitoring of performance and impact of the project. The Agrarian Research and Training Institute (ARTI) carried out continuous monitoring of irrigation and agricultural performance throughout the project's life. Also, baseline, midterm and final impact studies were carried out by ARTI and its collaborator, Cornell University. Several special studies on particular subjects were carried out by ARTI researchers and Cornell graduate students. Unfortunately, there was little periodic reporting of results, although the data were used in many individual studies. None of the results were used in activity planning. The major importance of these efforts was that ARTI and Cornell researchers and consultants were also involved in WMP's farmer organization program and thus could use these data to support changes in the R&M plans and procedures. Also, the publication efforts have had a major impact on the government agencies, government policies and farmers.

USAID commissioned independent midterm and final evaluations by outside consultants. The midterm evaluation was important in reorienting the project in more useful directions.

3. WIIP plans did not incorporate baseline or midterm studies or evaluations. However, the donor asked IIMI to undertake studies to help with selected aspects of implementation. The results of the first phase of IIMI's work were made available only in 1990, long after many aspects of the project planning were firmly set. Thus they have had little influence on the R&M process.
4. MIRP did not include baseline or midterm studies or evaluations. A final evaluation is being carried out at present. Changes that have occurred have largely been due to pressures from outside agencies and from the observable success of ISMP.
5. Documentation of lessons learned was explicitly built into the design of ISMP. Different combinations of inputs were to be used in different schemes and a comprehensive monitoring system used to document the differing processes and results. During implementation, changes were made in the project design that negated the value of the planned experiment.

A two-year, highly detailed pre-project study was carried out to provide both baseline and diagnostic data on the systems where R&M were to be carried out. Unfortunately, the results came too late to help with project planning and since no final impact assessment is planned, they will not be useful as a baseline study.

ISMP incorporated a research component that completed individual studies on particular issues of general relevance to irrigation management in Sri Lanka rather than solve problems for ISMP. However, two of the studies funded by ISMP were directed toward learning lessons from all the R&M projects. These studies form the basis for this paper.

ISMP designed a monitoring system for irrigation system management that would also produce data for project management. Although the first version was put in place in 1989, it proved unworkable. A much improved system was put in place in 1991, very late in the project.

Finally, USAID commissioned an internal review and an external midterm evaluation that together caused important changes in implementation. No USAID-commissioned final evaluation will be carried out.

None of these efforts have provided effective monitoring and evaluation of the progress and impact of the project as a whole during the whole implementation period. However, the multiplicity of efforts has made ISMP a well-documented project that could learn lessons and adapt to its needs as it progressed.

Only WMP and ISMP had explicit mechanisms by which progress and impact could be evaluated while the project was underway. These mechanisms allowed important lessons learned to be incorporated into project implementation. All the others made at least some token provision to document lessons learned.

At first glance, it may appear that allocation of funds for elaborate data collection and evaluation efforts is not worthwhile. The evidence from these projects shows that, when combined with appropriate management mechanisms, these efforts allow for adjustments to local conditions and thus greatly improve cost-effectiveness. The two most cost-effective projects are those that made the greatest efforts to monitor and evaluate impacts.

Donor Funding

In Sri Lanka, as in many other developing countries, most R&M activities have been financed in part with foreign funds. One result is that donors have greatly influenced the projects. The results of foreign intervention in Sri Lanka have been mixed:

- Many ideas underlying the successful approaches to R&M have come from foreign technical assistance. For example, the concept of “pragmatic rehabilitation” introduced in WMP was created by foreign experts and local project implementors working out the problems in Gal Oya. Similarly, the computer-based O&M systems introduced under WMP, ISMP, and MIRP originated with foreign experts.
- On the other hand, the donors have also imposed management conditions that have caused problems. One of the main problems has been donor insistence on five-year projects. None of the five R&M projects were completed within the planned five-year span, generally for good reasons. In addition, in every project, design efforts were begun very soon after the start of the project to complete the design and construction as fast as possible. Thus, even where farmer involvement was desired, it was neglected in favor of getting the construction work finished quickly.

As good financial managers, donors are concerned to know how much funding is needed and on what the funds will be spent before they authorize the expenditures. This means that they would prefer that planning be completed before committing the money and beginning the project. A need

to complete R&M plans to get financing is a root cause for the superficial planning studies reported above.

SYNTHESIS OF THE FINDINGS

Characteristics of a Cost-Effective R&M Project

Based on the findings reported above, a cost-effective R&M project would have the following characteristics:

1. An appropriate balance between software, including both institutional development and O&M system development, and hardware to support the O&M systems; this balance is necessary to ensure that the management changes are made to make the physical system changes functional.
2. Adequate diagnostic studies of the individual schemes, including good assessments of water availability; these are needed for selection of a scheme for R&M and for project planning; these studies should not be entrusted solely to consultants who can spend only a few weeks on them.
3. R&M plans tailored to individual schemes not only through adequate studies but also through consultation with farmers and operating system personnel.
4. Explicit provisions for reviewing and changing plans during implementation as lessons are learned about the particular scheme and the strategy being followed; for this purpose, mechanisms that evaluate the progress and impact of the R&M and feed the information back to project implementors, funders, and overseers are needed.
5. Mechanisms that allow for the participation of operating personnel in selection of technology and design and mechanisms that provide for the participation of farmers in design and construction to ensure that their interests are adequately reflected in the outcome.
6. Effective farmer organizations created before planning begins so that farmer participation can be fully effective.
7. Realistic time scheduling that makes adequate provision for project start-up and that allows for unforeseen disturbances and delays and for changes.

This listing is not new. It agrees substantially with the listing of characteristics given by conferences in 1986 (Haider 1987) and 1989 (Hydraulics Research 1989) and others. What is spelled out here is what these findings mean for R&M projects in Sri Lanka. In the next section, therefore, the way a cost-effective R&M project should be planned and implemented is considered in more detail.

Achieving Cost-Effective R&M

Table 2.3 shows a framework which embodies the conclusions reported above. For Project Planning, Project Implementation, and Project Management, Table 2.3 lists steps and principles which, if followed, should ensure cost-effective R&M. This section expands on this framework.

Project Planning

SELECTION CRITERIA FOR R&M. The performance of all irrigation systems deteriorates over time. The general goal of R&M is to improve system performance. Therefore, systems should be selected for R&M when there is both the need and opportunity to significantly improve performance through R&M.

There are clear tradeoffs between maintenance and rehabilitation; greater investment in maintenance implies slower deterioration of performance and longer periods between R&M. On the other hand, changing demands on the system from a larger number of users or from changing cropping patterns may require system-wide changes only possible through R&M. Also, R&M is usually required to benefit fully from the opportunities to improve performance by using new technologies.

Table 2.3. Conceptual framework for achieving cost-effective R&M.

Project Planning

1. Selection criteria for R&M determined.
2. Diagnostic studies conducted: current status measured against goals of farmers and operators.
3. Operational and maintenance constraints identified.
4. Water availability studies carried out.
5. Suitable technology identified in consultation with system operators and farmers.
6. Desired institutional and management changes identified.
7. Adequate farmer contribution to costs negotiated.
8. Adequate funding for the different components allocated.
9. Agreement with farmers and operating agency reached and incorporated into final report.

Project Implementation

1. Farmer organizations created and strengthened.
2. Orientation and training for agency personnel and farmers conducted.
3. Operating agency strengthened for implementing rehabilitation.
4. Farmer involvement in design, construction, operation and maintenance planned and implemented.
5. Development of the O&M system to be used after the project.
6. Use of appropriate design principles and construction methods.
7. Flexibility in implementation methods.

Project Management

1. Work plan and schedule developed: sequencing of activities and allowing sufficient time.
2. Financial management, including tendering and procurement.
3. Progress and impact monitoring, evaluation and feedback.
4. Flexibility in planning and oversight to respond to lessons learned and local conditions.
5. Midterm external evaluation for project changes.
6. Final evaluation and completion of report to document lessons for other projects.

Ideally, therefore, R&M of a system should be planned well ahead of time to take advantage of the tradeoffs involved (less maintenance to save resources for R&M, etc.). This is simply the irrigation expression of planning for capital replacement (depreciation) that is standard practice for businesses and other agencies around the world.

Unfortunately, such planning is rarely done. Without individual system planning of this sort, agency personnel or others charged with implementing R&M projects must evaluate systems as candidates for R&M investments. It is assumed that, in a developing country, R&M work will be initiated by a government or private agency rather than by the farmers themselves. In this case, the funding or implementing agency must develop criteria for systematically identifying schemes that are candidates for R&M.

As will be made clear, the principles proposed here delay the conclusive decision to undertake R&M of a system until the full planning process has been completed. Therefore, the initial identification of candidate irrigation systems can be made on any reasonable basis, including visible physical deterioration, expressions of interest from farmers, political expediency, etc.

A major problem is to select one candidate scheme over others; that is, it may be necessary to decide which candidates will be better investments. This issue is not discussed in depth here; instead what is focused is how to achieve cost-effective R&M once a scheme is selected.

DIAGNOSTIC STUDIES. Once a system is designated as a candidate for R&M, diagnostic studies must be initiated to get the necessary information for evaluation of the potential effects of R&M and for planning R&M.

Evaluation of a system for R&M requires answering two key questions:

- What is the performance level of the system now and what could it be following R&M?
- What are the costs and benefits of alternative R&M strategies?

First, it is necessary to define "performance" and decide how to evaluate it. No general definition of "performance" can be given because the objectives of each scheme are unique to that scheme. For example, irrigation system performance necessarily incorporates ability to deliver water to farmers' fields, and remove it when there is excess. However, the standards by which water delivery performance is to be judged depend upon the crop needs and the availability of water. For example, a water-abundant system may not require high reliability in scheduling but may require good drainage if farmers are growing crops that do not tolerate excess water. In another system, farmers may grow water-tolerant crops, such as rice, which do not require drainage. In a third system, water availability may be low and reliability of water delivery may be very important.

It follows then that the first task in selecting a system is to confer with the farmers (and other users, if any) to determine their performance goals for the system. Once the goals are determined, determination of current performance levels relative to those goals is straightforward.

OPERATIONAL AND MAINTENANCE CONSTRAINTS. The next step is the determination of the causes for lower-than-desired performance levels. This step requires investigation of: a) faults and problems with the water acquisition and conveyance system, b) faults and problems with the systems for making seasonal and daily operating decisions, and c) faults and problems with other support systems.

In the past, there has been a tendency to assume that deterioration of the conveyance system is the cause of poor performance. In fact, however, nonfunctioning structures may have been broken by farmers in an attempt to compensate for poor operations. Eroded canals may be a symptom of failure to undertake even simple and cheap maintenance efforts. Fixing the structures

without simultaneously fixing these management problems will clearly not result in the expected benefits. Thus, the investigation of causes must not be limited to physical inspection of the system but must also include an inquiry into O&M systems and the institutional structure that supports O&M.

The investigation should rely heavily on interpretations given by system operators and farmers since they have extensive experience with the system.

WATER AVAILABILITY STUDIES. Particular attention must be paid to system hydrology. The Sri Lankan experience is that several R&M investments have been wastes of money because of faulty estimates of water availability. If adequate water is not available, R&M should not be considered. As with investigation into O&M problems, weight should be given to the experiences of farmers and system operators who have had to deal with system water problems. The hydrological investigations should not rely primarily on the investigations carried out for the original design of the system. The hydrology has almost certainly changed with development of the area for agriculture.

SELECTION OF SUITABLE TECHNOLOGY. Once the underlying management and structural problems have been determined, selection of technologies is necessary to solve the problems. The selection of a solution must take into account the opinions and knowledge of farmers, who will have to live with the system and may have to pay for the R&M work, and of system operators who must make it work. However, outside experts can play a significant role in identifying technological alternatives that farmers and system operators may not be aware of.

The best approach then is:

1. Experts identify and cost alternative solutions to the system problems.
2. Experts discuss the alternatives with the system operators to learn what would be appropriate for them and what additional support they would need to make the various options function.
3. Experts negotiate with farmers over which approach is most cost-effective.

This approach means that all three sets of experiences are brought to bear on the problem to ensure the suitability of the approach to local needs.

INSTITUTIONAL AND MANAGEMENT CHANGES. Adoption of particular technologies requires concurrent adoption of appropriate O&M management practices. To ensure that the appropriate balance between software and hardware components is maintained, proposals for new technologies to solve system problems must also describe the concomitant changes needed in O&M systems and in supporting institutions. Thus the discussions between experts and system operators and farmers must include discussion of the management changes needed and the costs of those changes.

FARMER CONTRIBUTION TO COSTS. To ensure cost-effectiveness, the farmers should have a financial interest in the R&M activities; that is, farmers should be made responsible for paying at least part of the cost. The amount should be such that they cannot make their contribution solely with labor; labor is a relatively low valued commodity. If farmers must commit some part of storable resources (cash or others), they are likely to be much more careful in what expenditures they approve. In the Philippines' successful program for the R&M of communal irrigation systems,

farmers are made responsible for covering significant portions of the R&M construction costs. This provision has made the responsible agency very careful with its recommendations and planning (Isles et al. 1987).

Therefore, the negotiations between the experts and the farmers should include negotiation of the costs that will be paid by the farmers. It should be noted that it is generally not possible to conclude a negotiation with farmers unless the farmers are represented by an organization. *An effective farmer organization is therefore a prerequisite to completion of this step.*

ALLOCATION OF ADEQUATE FUNDS TO PROJECT COMPONENTS. The Sri Lankan experience is that unless funds are specifically earmarked for a particular purpose in the project document, the government can rarely provide extra funding for necessary activities. Thus, if the selected R&M strategy requires extra assistance in agriculture, project funding for this assistance must be explicitly allocated. Funds should be explicitly provided for O&M system development, training of the O&M staff and farmers, for institutional development of both the farmer organizations and the agency, and for project monitoring and evaluation.

AGREEMENT WITH FARMERS AND OPERATING AGENCY. The findings of the diagnostic studies, the planned O&M systems, the agreed technologies to support the O&M systems, the proposed initial budget, and the agreement of farmers to the plans and to pay their share of the costs should be incorporated into a final report. Only if all these are accomplished and a formal agreement is reached with the farmers should the scheme be taken up for R&M.

If the interests of both farmers and system operators are satisfied and the farmers are agreeable to paying a significant portion of the costs, the R&M proposal can be said to be "cost-effective." That is, if the negotiations with farmers are done seriously, it is the farmers who can judge whether the benefits are worth the costs. In this case, further pre-project economic analysis may not be necessary. *Concluding a formal agreement with the farmers is thus the key step in this process.*

However, if the farmers are not paying the full cost or if the agency will be lending funds to the farmers, there remains the question whether the proposed R&M work should be done on this scheme or on another. For this purpose, it may be necessary to prepare an economic analysis of the proposed project to satisfy the funding agency.

Project Implementation

At completion of the planning process described above, not only will it have been determined that the particular scheme will have an R&M project, but also that the initial strategy for R&M will have been selected, that a budget will have been prepared and funded, and that both the system operators and farmers will have become aware of and committed to the project.

FARMER ORGANIZATIONS. As pointed out already, the existence of an effective farmer organization is a prerequisite for the completion of project planning. In Sri Lanka, however, not all schemes have effective farmer organizations. Although government programs exist to create farmer organizations, the programs have not been very effective except where R&M project funds have been made available.

There are two possible solutions:

- Separate programs for the creation of farmer organizations from R&M projects should be developed. If the government cannot adequately fund the farmer organization programs, it could seek donor funding specifically for that purpose.

- A period should be provided at the beginning of the project to create or strengthen farmer organizations to a level where they can play their parts in an R&M project. This would delay the planning of R&M for particular schemes for one to two years. This was the approach adopted by the Philippines in their successful R&M project for communal irrigation systems.

The authors prefer that the farmer organization program be separated and that the existence of effective farmer organizations be made a precondition for consideration of a scheme as a candidate for R&M. In other words, it is recommended that the agency not even put a scheme on its list of candidates for R&M unless effective farmer organizations exist.

ORIENTATION AND TRAINING FOR PARTICIPANTS. A key problem in prior R&M projects is that implementation was delayed by lack of coordination among various agencies and between agencies and farmers. Efforts made at the beginning of the project and at intervals during the project to get all the participants together to inform them of what will happen and to develop common understandings are worthwhile. These efforts might include planning workshops and the use of other interactive methods.

Also, a training needs assessment should be carried out from the very beginning of the project so that any special training needs can be catered to expeditiously.

OPERATING AGENCY STRENGTHENING FOR IMPLEMENTING R&M. Close coordination between system operators and staff implementing the R&M is essential so that operators' needs and experience can be fully incorporated into the project. Therefore, the R&M project should not be undertaken by an outside agency but by the operating agency itself.

However, system operating staff can rarely undertake an R&M project in addition to their operational duties. Therefore, additional personnel and additional equipment and transport must be provided. Training of personnel, if needed, should be provided early in the project.

FARMER INVOLVEMENT IN O&M, DESIGN, AND CONSTRUCTION. Farmer involvement in O&M, design and construction is necessary to ensure that farmer experience with the system is incorporated into the work, to let farmers help ensure the cost-effectiveness of the project, and to ensure farmer commitment to making the project work.

Farmer involvement in O&M is discussed in many of the sources and will not be discussed at length here. Techniques used successfully in Sri Lanka for effective farmer involvement in design include: a) joint walk-throughs of field and distributary channels in which engineers and farmers discuss and resolve issues prior to undertaking detailed designs, and b) meetings with farmers to present and discuss the details of proposed designs prior to their completion. Awarding contracts to farmer organizations for R&M construction on their own channels has proven to be an effective way of getting farmer involvement in construction.

The use of these techniques may require changes in procedures and job activities for irrigation agency personnel. When changes are needed, the procedures involved must be planned, and the field personnel must be trained.

The use of these techniques also requires more time, particularly for design work, than if these activities are carried out without farmer involvement. The authors have argued earlier that farmer involvement will ensure good results. It is suggested, although it cannot be proved, that well-managed farmer involvement in design will make construction flow more smoothly and more rapidly. Thus, some of the extra time spent on design may be recovered during construction.

O&M SYSTEM DEVELOPMENT. One key finding is that O&M system development is crucial to effective R&M. In some R&M projects, O&M system development has been neglected in favor of design and construction work. The O&M strategy to be followed after completion of the project must be determined before beginning design activities. Such determination of the O&M system first not only ensures that design criteria match O&M requirements but also ensures that appropriate attention will be paid to O&M system development.

USE OF COST-EFFECTIVE DESIGN PRINCIPLES AND CONSTRUCTION METHODS. Construction normally absorbs the bulk of the resources for R&M. It is important that the specifics of design and construction be appropriate to needs and be based on experience in the local setting. For Sri Lanka, for example, WMP established that rubble packing is as effective as retaining walls for some purposes and is far cheaper. ISMP established that, in some conditions, the use of historical water levels for design is more accurate than the use of levels calculated from original design criteria. The latter are likely to call for greater canal capacity thus calling for greater expense. Similarly, ISMP showed that drop structures could be used as effectively for discharge measurements as separate measuring structures thus reducing the number of structures required and so reducing costs.

The particular cost-effective techniques to be used are necessarily adapted to local conditions and a complete list cannot be given. However, not only should project designers and managers constantly search for new ideas like those mentioned, but also they should encourage the agency staff and farmers to make suggestions. Many location-specific cost-saving techniques originated from the staff and farmers on the spot.

FLEXIBILITY IN IMPLEMENTATION. Making major and minor modifications in implementation methods and procedures in response to lessons learned is a key characteristic of cost-effective R&M projects. Project managers must be prepared to modify methods and procedures to fit different local conditions in different parts of the scheme and to use more effective methods and technologies discovered as experience grows. A flexible approach to implementation also helps to encourage innovation by staff and farmers since they know that good ideas will be adopted.

Project Management

WORK PLAN AND SCHEDULE. As for any major project, it is essential that early in the project a detailed work plan be developed. As pointed out earlier, this should be done with the involvement of all the participants so that it reflects the real implementation requirements and all are familiar with the plan.

The biggest problem the authors found with project work plans was that inadequate time was allowed for project activities. Scheduling should incorporate the following commonly neglected principles:

- Sufficient time must be allowed for project start-up so that all participants can be informed and trained properly. Project start-up activities often require six months to a year.
- Time should be allowed for unforeseen delays, particularly in construction work. A rule of thumb might be to add 50 percent to the time estimated for optimistic construction schedules.
- Farmer involvement in design will require more time than having it done by technical specialists alone. Extra time must be allowed.

FINANCIAL MANAGEMENT. Financial management is a key ingredient of project management. For an R&M project planned and implemented as recommended here, financial reports should be provided to farmer organizations because the farmers have a financial interest in the conduct of the project.

Also, tendering and contracting procedures have sometimes been a major cause of delays; streamlining such procedures may be important in keeping to the schedule.

PROGRESS AND IMPACT MONITORING, EVALUATION AND FEEDBACK. It is essential that an adequate monitoring and evaluation system is created early in the project. This system should not only report on the progress of activities but also should provide regular feedback to project managers on the cumulative impact of activities. To ensure that the information is objective some should be prepared by outsiders. This information is essential not only for normal project management but, more importantly, to make it possible to adapt implementation methods and procedures to the lessons being learned during the project itself.

FLEXIBILITY IN PLANNING AND OVERSIGHT. Just as flexibility in implementation methods is needed, willingness to modify the work plan and R&M strategy is necessary. Plans, including basic strategies, should be reviewed and revised at appropriate intervals based on information from experience gained during project implementation, from the monitoring and evaluation system and from outside experts consulted at midterm or another appropriate time.

MIDTERM EXTERNAL EVALUATION. WMP and ISMP have clearly shown the value of a midterm evaluation carried out by external experts. When done properly, this evaluation is based more on the ideas and information held by the project participants than on the outside experts' knowledge. The function of the experts is to collect and consolidate these ideas and information and present them in a clearly articulated form so that project participants can make the necessary changes in plans and implementation methods.

FINAL EVALUATION AND COMPLETION REPORT. Finally, it is important that the project implementors prepare a completion report and that a final evaluation be done, preferably by outsiders. While these do not contribute directly to achieving cost-effective R&M on the particular scheme reported on, they do provide information that will be of use elsewhere, including particular technical approaches learned during the project and particular management lessons learned. An economic evaluation should be part of the final evaluation not only to satisfy funding agency requirements but also to provide a check to the ideas presented in this paper.

Implementing the Process with Donor Funds

The approach to achieving cost-effective R&M outlined above does not allow specification of exactly which systems will undergo R&M until after detailed investigations and negotiations with farmers. Also, flexibility during implementation is advocated. But changed plans mean changes in funding requirements. Both conditions make it difficult to be precise about funds needed and what they will be spent for prior to beginning the project. This approach does not agree with the usual approaches taken by donors.

It is suggested that the solution has three parts:

1. The irrigation agencies should set up small units whose function is to investigate systems that are candidates for R&M and begin tentative negotiations with farmers. This can be an ongoing process.
2. The output of these units should be used to decide which systems will be proposed for R&M funding from a donor.
3. The government should demand of donors that the required flexibility be incorporated into project plans.

It is suggested that if the government makes the effort to plan R&M in this way, rather than waiting until there is an expression of interest from the donors, the government will be in a strong negotiating position. There will still be a place for foreign technical assistance to provide advice on new technologies, but the fundamentals of the R&M plans for each system will be set by the Sri Lankan agencies and farmers on that system rather than by outside consultants.

CONCLUSION

In this paper the authors have analyzed Sri Lanka's 15 years of experience with projects for the rehabilitation and modernization of major irrigation systems to define a set of principles and a process that they believe can ensure *cost-effective* R&M. Although the data have been drawn only from Sri Lanka, the factors focused on are aspects of process and management rather than location-specific technical factors. Therefore, the authors believe that these principles are valid not only for Sri Lanka but also for many other developing countries.

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CHAPTER 3

Mogtêdo: The Sociotechnical Evolution of an Overexpanding Irrigation Scheme

Hilmy Sally

INTRODUCTION

BURKINA FASO is a landlocked country of 274,000 km², situated between latitudes 10°N and 15°N in the Sudano-Sahelian agroclimatic zone, characterized by an annual rainfall of between 400 and 1,200 mm.

Irrigation development began in the 1960s with a view to help meet the food requirements of the country's 9 million people by supplementing the production from traditional rain-fed farming. Irrigated agriculture is presently estimated to cover about 16,000 hectares (ha), or about 10 percent of the irrigation potential. This area remains modest compared to the nearly 2.6 million ha of rain-fed agriculture.

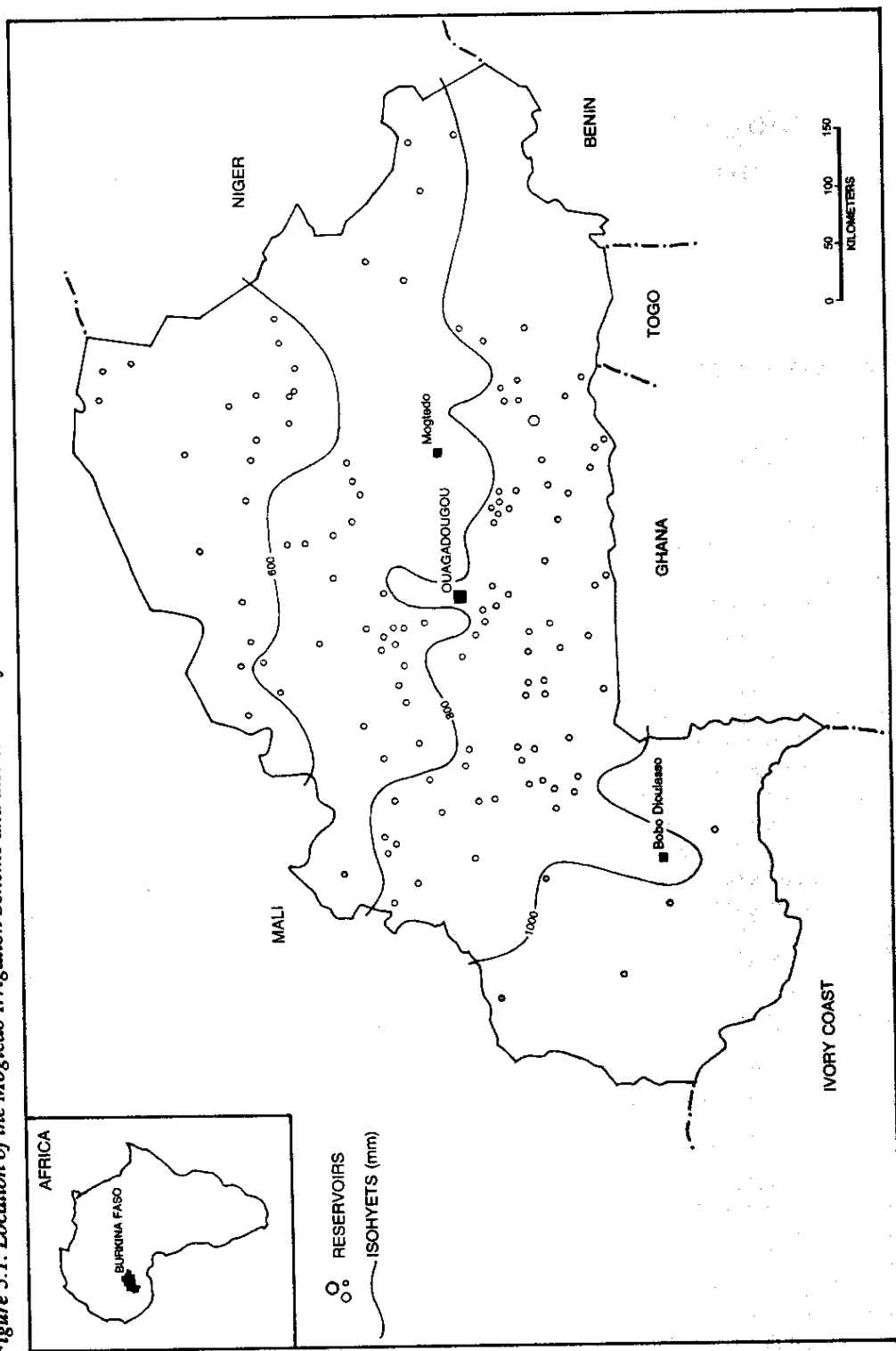
In the current socioeconomic context, dominated by the need to adhere to structural adjustment programs, the progressive transfer of management responsibilities in irrigation schemes to the beneficiaries is increasingly becoming a feature of irrigation development policy in Burkina Faso. The IIMI-Burkina Faso country program aims to strengthen the capacity of national partner institutions to improve and sustain the performance of small-scale, reservoir-based village irrigation schemes through collaborative research, training, and information dissemination. IIMI acts as the executing agency of a 4-year project financed through a technical assistance grant from the African Development Bank (AfDB) to the Government of Burkina Faso.

The project commenced in April 1991. This paper reports on the results of the first 18 months of work in Mogtêdo, one of the five small-scale, reservoir-based irrigation schemes where IIMI is conducting field research. It also draws on the more generic work carried out on the institutional and legal frameworks related to the irrigation sector in the country.

The Mogtêdo Irrigation Scheme, commissioned in 1968, is one of the oldest in Burkina Faso. It is typical of small, reservoir-based village irrigation schemes managed by farmer organizations with technical assistance and support services provided by government agencies. The scheme has undergone much change in the nearly 25 years of its existence. The initial reticence of the farmers vis-à-vis irrigation gave way to an avid interest in acquiring an irrigated plot. This resulted in a progressive expansion, formal as well as informal, of the irrigated area which continues even to this day. Much of this expansion however did not follow any rational development plan and escaped all supervision or control on the part of the state, which remains the legal proprietor of the reservoir, the irrigation infrastructure as well as the irrigated land. A deteriorating physical infrastructure and water piracy exacerbate system management. The farmer organization implicitly condones this situation by its inability or unwillingness to act against it.

The paper identifies the internal and external factors which are likely to have contributed to the present situation. It analyzes the mobilization and storage of the water resource, assesses operational practices relating to water conveyance, distribution and on-farm irrigation, analyzes

Figure 3.1. Location of the Mogtédou Irrigation Scheme and distribution of small dams and reservoirs in Burkina Faso.



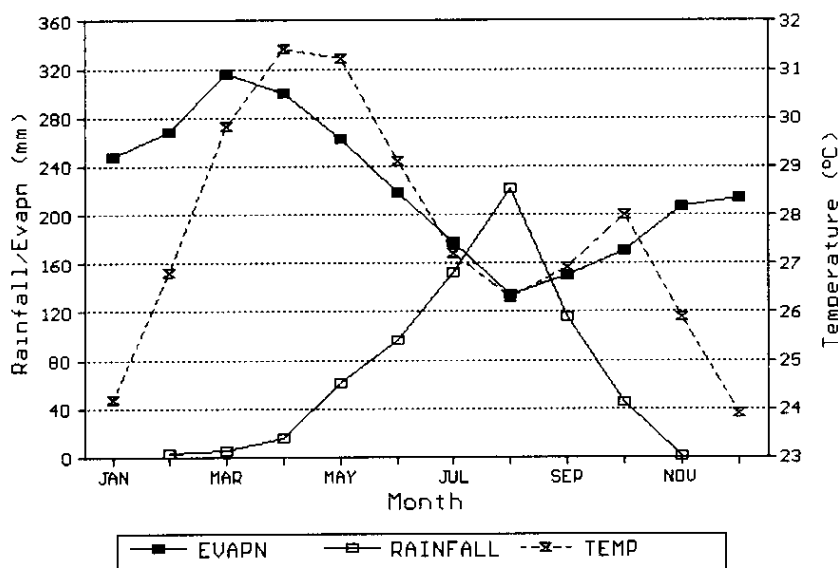
the formal and informal organizational arrangements in the systems, and reviews the institutional context. The interactions among the different actors of the system and the conflicts between the traditional seats of authority and "modern" administration are explored. Some key physical, institutional and organizational factors likely to contribute to ensuring the sustainability of irrigation schemes of this type are finally identified. This is especially in view of the current irrigation development policy in Burkina Faso which emphasizes the progressive transfer of management responsibilities to the beneficiaries.

THE MOGTÉDO IRRIGATION SCHEME

Location and Climate

The Mogtédou Irrigation Scheme is located near the village of the same name, 85 km east of Ouagadougou, the capital of Burkina Faso. The Mogtédou Reservoir is one of over 700 small reservoirs in the country (Figure 3.1) providing people and livestock with some degree of security against climatic variability. Use of the stored water resource for irrigated agriculture was rather limited until formal irrigation schemes were begun to be developed around these small dams and reservoirs in the 1960s.

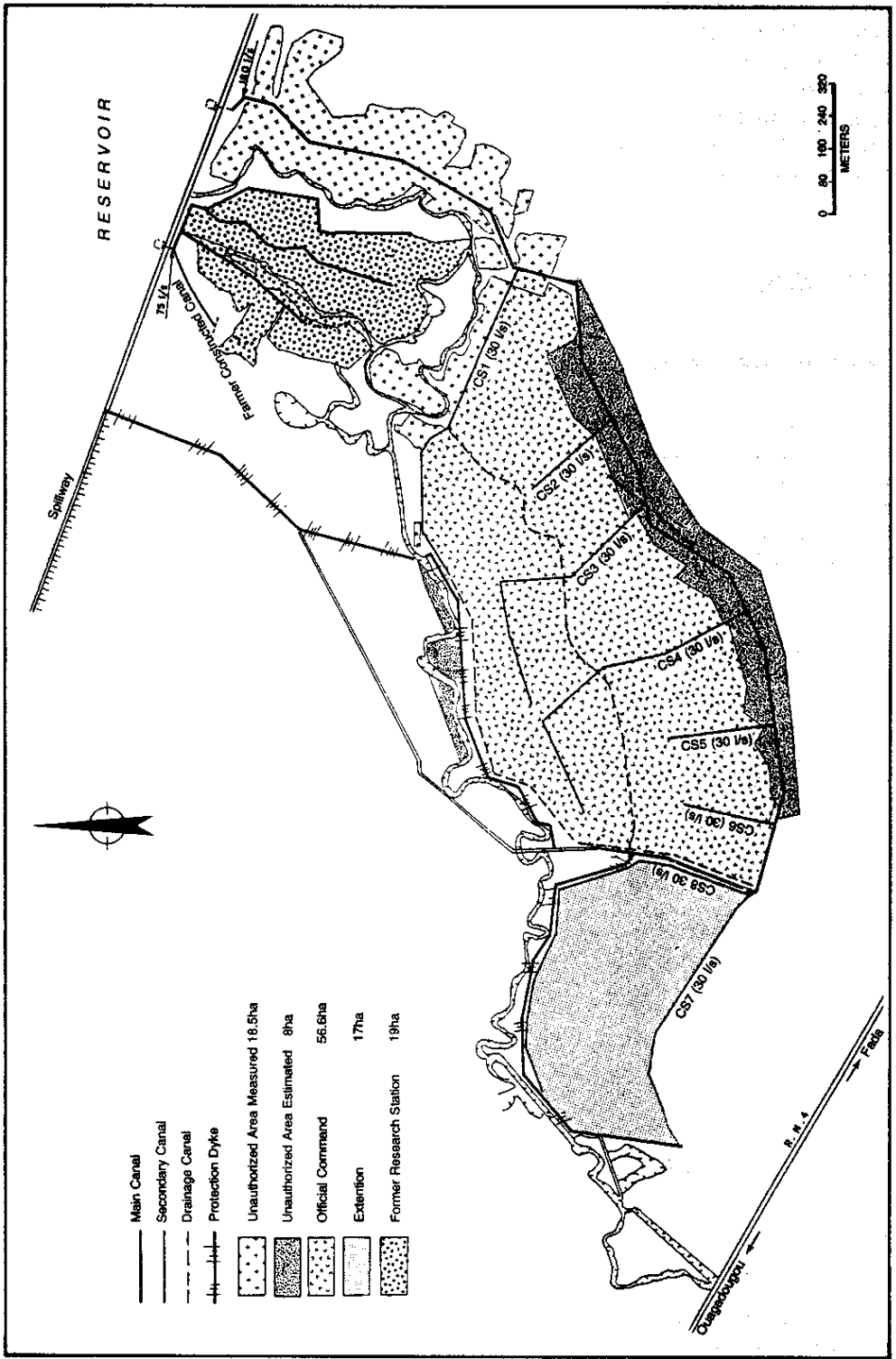
Figure 3.2. Average rainfall, pan evaporation and temperature, Mogtédou, 1971–80.



Note: Evapn = Pan evaporation.

The climate in the area is of the Sudano-Sahelian type with a single rainy season from May to September and mean annual rainfall between 700 and 800 mm (Figure 3.2). The hottest months

Figure 3.3. The Mogtêdo Irrigation Scheme: Formal and informal irrigated areas.



are April and May when temperatures during the day can attain 45°C, whereas in January, the coldest month, minimum temperatures often fall below 10°C.

The Dam and Reservoir

The Mogtédó Reservoir was created by constructing a 5-m high earth dam, 2,600 m in length, across the Bomboré, a tributary of the Nakambé River (formerly called White Volta). Its catchment area is approximately 500 km². The dam is in good condition, apart from the loss of some riprap on the upstream face and a few traces of erosion on the downstream face. However, the 600-m long concrete spillway is threatened by progressive erosion of the spill tail channel which has already undermined the antierosive dike located immediately downstream of the main spillway.

The reservoir, whose capacity was assumed to be 2.9 million m³ (until 1991-92), provides irrigation water to land on the left and right banks of the river. The official irrigated command area is made up of two blocks (57 ha and 17 ha) on the left bank side and a single 19-ha block on the right bank, developed progressively between 1964 and 1975. Large extents of informally irrigated land within and around the "official" command area have gradually come into being since 1985 (Figure 3.3) and add to the complexity of system management. Surveys conducted by IIMI in 1991 and 1992 have revealed that the extent of informal irrigation varied from sector to sector but was always of the order of 30 ha.

Irrigation and Drainage Network

A 2,500 m long, 180 l/s capacity, concrete-lined main canal conveys water from the reservoir through the left bank command area. Water is then distributed to the farmers' fields via a network of eight secondary canals (also lined) and 64 unlined tertiary canals. The first six secondary canals, S1 to S6, are equipped with calibrated distributors (or "modules") of 30 l/s capacity each. Regulation of water level in the main canal is ensured by a series of concrete weirs. The gates at the heads of the tertiary canals no longer exist. The irrigated area on the right bank is fed by 4 secondary canals taking off immediately downstream of a 75 l/s sluice from the reservoir.

Table 3.1 summarizes the characteristics and present state of the secondary canals of the left bank area, the primary focus of this paper.

The drainage network is practically nonfunctional and large extents of land in the central zone of the command area as well as low-lying areas in the "extension" remain waterlogged. Furthermore, some drains have even been transformed into irrigation canals!

Soils and Crops

The scheme was originally planned for double cropping of rice on the basis of soil surveys carried out in the early 1960s which indicated the predominance of hydromorphic soils (Gavaud and Pereira-Barreto 1961) in the area. Extensive in-situ tests carried out on the IRAT (Institut de Recherche Agronomique Tropicale) experimental farm established on the right bank area between 1964 and 1970 revealed that the first 40 to 60 cm of soil were in fact more permeable than was initially thought. Hence, diversified crops such as onion, tomato, chili and other vegetable crops

Table 3.1. Inventory of secondary canals in the left bank area of the Mogtédo Irrigation Scheme.

Canal	Length (m)	Discharge capacity (l/s)	Number of tertiary canals	Irrigated area (ha)	Present state of canal and structures
S1	810	30	9	15	* Subsidence of certain reaches * Deterioration of canal lining * Absence of control gates
S2	250	30	9	8	do.
S3	720	30	10	11	do.
S4	770	30	8	11	do.
S5	250	30	9	11	do.
S6	200	30	9	3	do.
S7 Extension	713	33	5	9	* Canal dilapidated due to poor quality of construction and frequent inundation * Demolition of canal lining * Absence of control gates * Seepage losses
S8 Extension	610	27	5	7	do.

were encouraged in the dry season. However, in certain low-lying zones, rice cultivation remains the only possible option in the dry season as well.

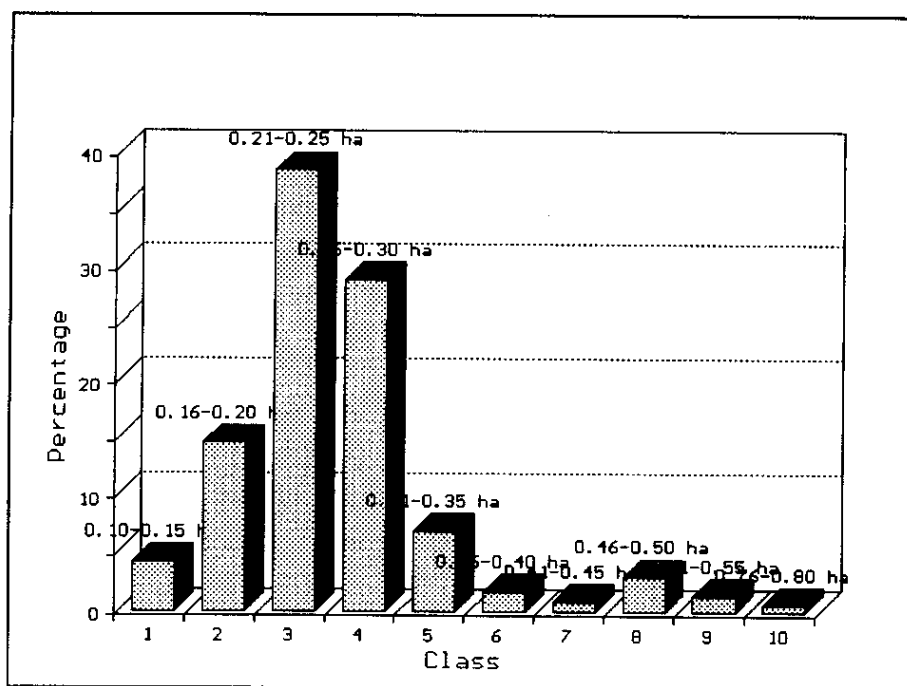
Landholdings

The size of the irrigated holdings is variable and relatively small. A survey carried out by IIMI in 1991 revealed that out of 374 landholdings, about 65 percent were between 0.20 and 0.30 ha in size. The size of the smallest holding was 0.10 ha, while that of the largest was 0.80 ha (Figure 3.4).

ORGANIZATIONAL STRUCTURE

According to existing legislation in the country, two distinct bodies are empowered to manage the irrigation scheme. One is, a *collective organization* made up of the beneficiaries to take charge of its day-to-day management. The responsibilities of this farmer organization, as described in the official texts, include organizing and carrying out irrigated agriculture, ensuring that technical norms and directives are respected, operating and maintaining the irrigation system, collecting user fees, facilitating the marketing of produce, and promoting a cooperative spirit among its members. The other body, a *management committee* made up of representatives of the provincial administration and the different state agencies with an interest in the scheme, and farmer representatives, is supposed to oversee the functioning of the farmer organization and to generally look after the interests of the state. This committee is entrusted with a consultative role concerning water distribution and marketing, and an executive role in matters relating to land allocations and land tenure.

Figure 3.4. Distribution of landholding size, Mogtédó, 1991.



In Mogtédó, immediately following the first round of land allocations in 1968, the farmer organization automatically obtained the status of a *cooperative*, headed by a Board of Directors. Although a draft constitution and associated statutes were drawn up to regulate its activities, they have not been formally adopted to date. In addition, the Management Committee too has hardly ever functioned effectively.

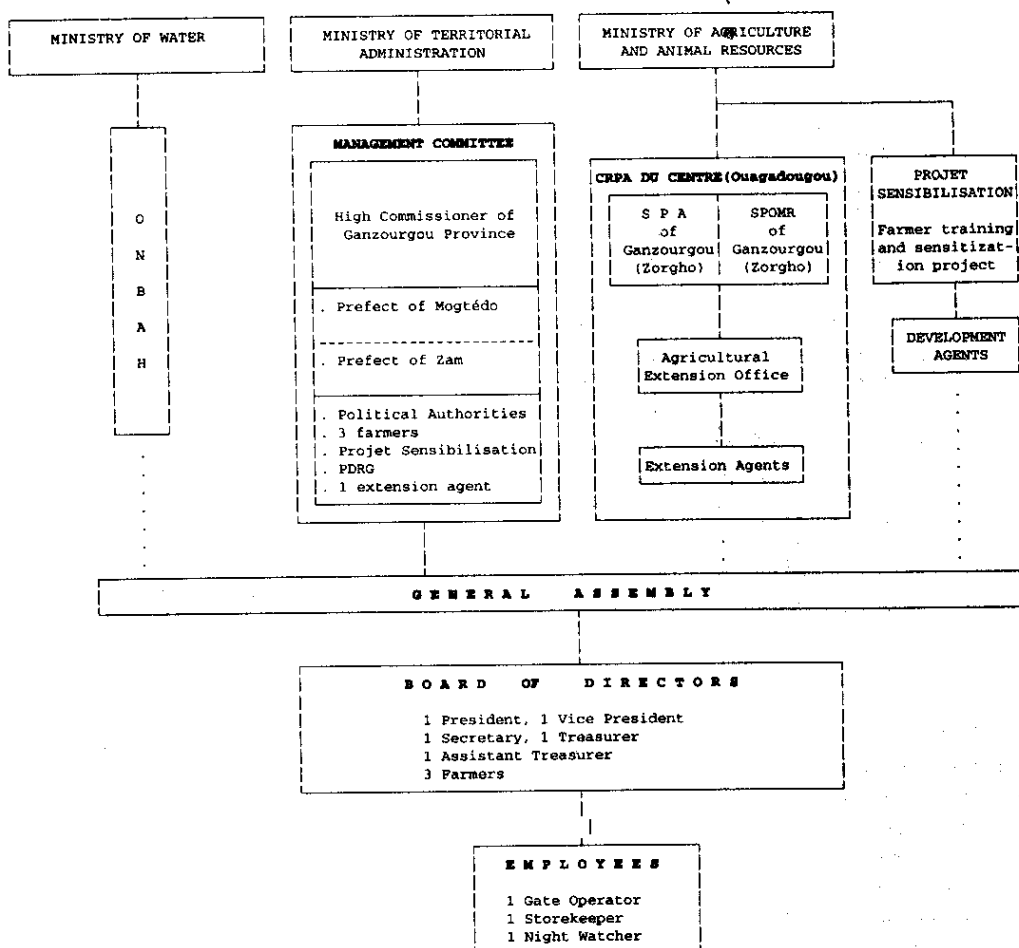
The Mogtédó Cooperative benefits from technical and administrative support from a number of agencies under the Ministry of Agriculture. Agricultural extension advice is provided by the Regional Agro-Pastoral Promotion Center (CRPA) which has two full-time field staff posted at the scheme, while the "Projet Sensibilisation" (a farmer training and sensitization project functioning under the same ministry) runs literacy programs and provides some training in administration and management. The National Development Bank and the National Agricultural Credit Agency extend credit facilities.

The principal focus of support staff from the extension services is on agronomic issues (e.g., ensuring supplies of seed, fertilizer and other inputs). Little attention is paid to optimum water use, doubtless because they lack technical training and skills in irrigation water management.

Actual system management operations are left in the hands of a farmer, employed part-time by the Cooperative as an *aiguadier* (a gate operator) and he carries out decisions made by the Board in this respect. In reality, his task is limited to opening of the main sluice in the morning and closing it in the evening (there being no irrigation at night) and to adjusting the setting of the calibrated distributors along the main canal.

The organizational chart of the Mogtédó Irrigation Scheme is presented in Figure 3.5.

Figure 3.5. Organizational chart of the Mogtédou Irrigation Scheme.



Legend :

ONBAH = Office National des Barrages et des
Aménagements Hydroagricoles.

CRPA = Centre Régional de Promotion Agro-pastorale.

SPA = Service Provincial de l'Agriculture.

SPOMR = Service Provincial à l'Organisation du Monde Rural.

PDRG = Projet de Développement Rural de Ganzourgou.

EVOLUTION OF LAND OCCUPANCY

Land Allocation Process and Land Tenure

When the state decides to invest in an irrigation system, it takes over the land on which the scheme is to be built. No compensation is paid for the expropriated land. After construction, the land is redistributed to the people following certain criteria. Previous occupants usually get priority. But

the beneficiaries are neither granted title deeds to their parcels nor are they guaranteed leaseholds for any period of time. The parcels may be withdrawn at any time, usually for not respecting any of the regulations governing farming activities which are in force.

Land allocation in an irrigation scheme is generally decided upon by a special commission made up of representatives of the Ministries of Water and Agriculture, local administrative and support services (CRPA, SPOMR, ONBAH, etc.), the political authorities, and the traditional village chiefs. Among the criteria used to determine the eligibility of applicants are:

- Whether the applicant had participated in the construction of the scheme.
- Whether s/he was already farming on the area now taken over for the irrigation scheme.
- Whether s/he had given an undertaking to adhere to the farmer organization, to pay all dues, and to conform to all technical and administrative directives.
- Family size, notably the number of able-bodied members capable of actually contributing to farming activities.

In Mogtédó, it appears that none of these criteria were determining factors, given the very small initial demand (in 1967) for irrigated land. Interviews carried out in 1991 reveal that participation in construction work or a financial contribution of 1,000 CFA francs (about US\$4) was sufficient to obtain a plot. There is no documentary evidence to prove that this was indeed the case, since no written records exist of the allocation proceedings. In the absence of records, it may be assumed that each beneficiary was only allocated a single plot, though it is highly unlikely that this rule was respected in the case of the subsequent extensions to the command area.

Formal and Informal Extensions

Being one of the earliest irrigation schemes in Burkina Faso, the growth of Mogtédó went hand in hand with the development of the political, legislative, and institutional frameworks governing irrigation development in the country. The attitudes of farmers vis-à-vis irrigated agriculture also evolved with time. Initial reticence, demonstrated by the fact that the allocation of land in 1967 only interested 38 beneficiaries, soon gave way to a great demand for irrigated plots. The progressive implementation of a number of formal and informal extensions to the irrigated area was a direct consequence.

Informal irrigation, obviously not conforming to any rational development plan, continues to expand in the absence of opposition from the Cooperative and of any supervision or control on the part of the Management Committee. This has led to the tacit acceptance of a variety of situations and practices which militate against the pursuit of sound irrigation management. Planning and monitoring become quasi-impossible in a situation where the extent of irrigated area is unknown because road and canal reservations and even drainage channels are cultivated. Unauthorized extraction of water from the main canal by pumping or siphoning takes place to the detriment of downstream water users, and water distribution does not follow any organized plan. The capacity of the existing canal network to cater to an ever-expanding area is limited. The indifference or inability on the part of the authorities (farmer organization as well as the state administration) to take effective remedial action clearly reflects the urgent need to correct existing weaknesses in the overall institutional framework related to the development and management of irrigation.

The different phases of development of the irrigation scheme are summarized in Table 3.2.

Figure 3.6. Updated blocking-out plan of the Mogtédo Irrigation System.

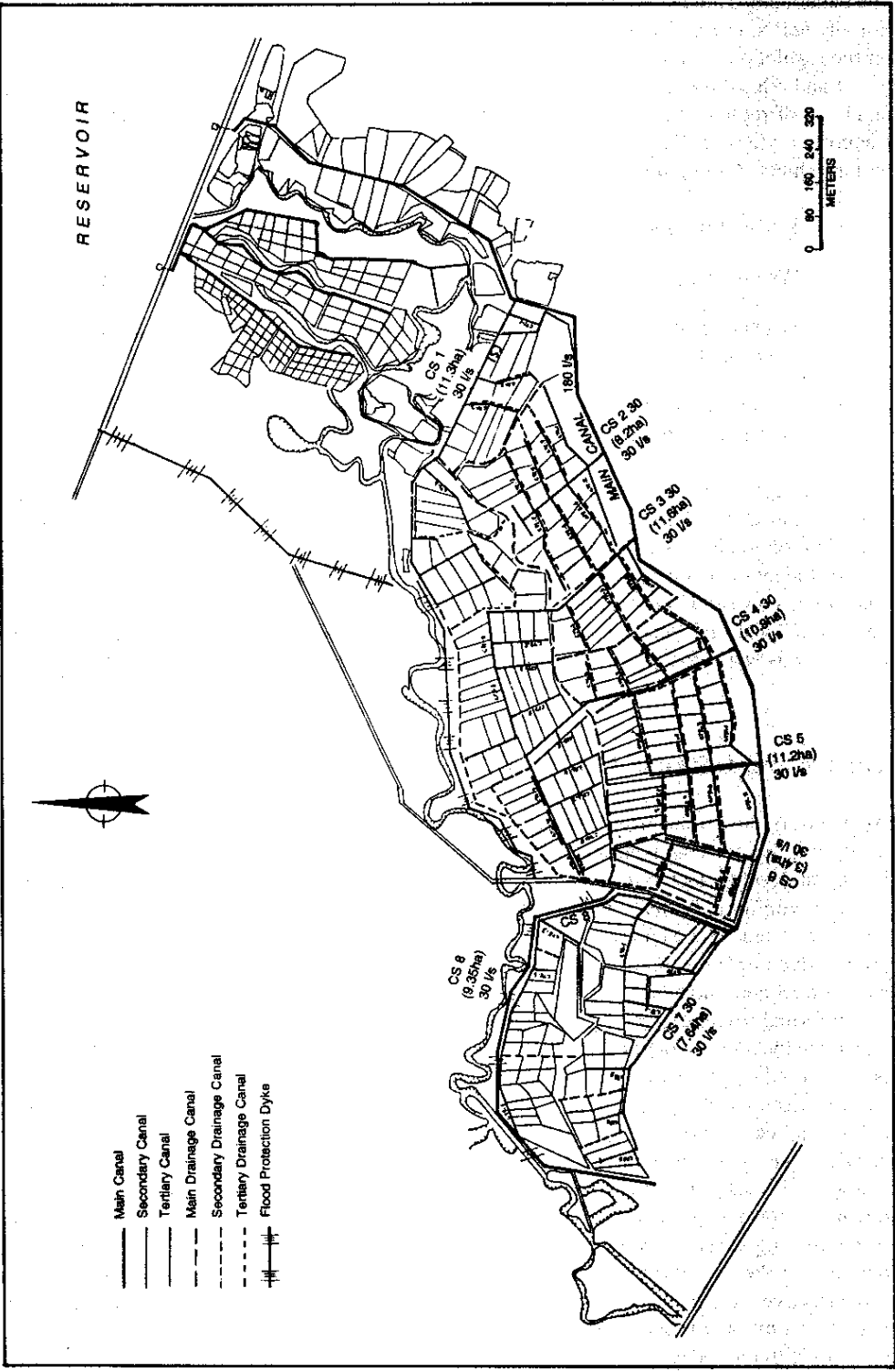


Table 3.2. Chronology of main events in the development of the Mogtédó Irrigation Scheme.

Year	Event
1963–64	Construction of barrage-reservoir; the reservoir is now known to have a storage capacity of 6.5 million m ³ (its capacity was initially thought to be 2.9 million m ³).
1964–74	Development of a 19-ha area on the right bank to serve as an experimental research station for the Institut de Recherche Agronomique Tropicale (IRAT). This area was blocked out and turned over to farmers after the closure of the station.
1967–68	Commissioning of 57 ha of irrigated command area on the left bank.
1974–75	Implementation of an extension of 17 ha at the tail end of the left bank system.
1984–85	Blocking out and turnover of IRAT experimental farm to farmers.
1985	Appearance of informal extensions along the head reach of the left bank main canal, along the main drainage channel, on canal reservations, around the reservoir boundary, etc.
1991	First attempt at quantifying magnitude of informal irrigation; IIMI survey in dry season, 1991, reveals an extent of nearly 30 ha, and more than 70 unauthorized pumping/siphoning locations. IIMI also carries out extensive topographic surveys to establish updated plan of canal network and irrigated area (Figure 3.6).
1991–92	Discovery (by IIMI) that accepted reservoir capacity is erroneous; subsequent bathymetric survey confirms reservoir capacity is 6.5 million m ³ .

Some Likely Causes for Uncontrolled Extension

The construction of the reservoir and the development of the irrigation scheme not only attracted a large number of migrants but also gave rise to a variety of associated economic activities. This migration largely contributed to the increase in the population of Mogtédó. The national census carried out in 1985 revealed that there were nearly 3,500 people in Mogtédó (compared to a population estimated to be less than 500 in the early 1960s).

Increased pressure on arable land and deteriorating soil quality adversely affect returns from rain-fed farming (though, as discussed later, farmers do attempt to improve productivity through innovative practices). On the other hand, beneficiaries of irrigated plots themselves claim that the relatively small size of their landholdings (cf. Figure 3.4) oblige them to seek supplementary means of satisfying their requirements. Acquiring (or extending) farm land with a more or less assured access to irrigation water constitutes one possible response to both the above situations, usually rendered even more attractive by connivance on the part of those bodies charged with management responsibilities on the scheme.

Among other reasons which could explain this phenomenon of uncontrolled extension are:

- The non-delimitation of the zone of influence of the reservoir and the irrigation system.
- Ineffective supervision and control on the part of the farmer organization and the state agencies.
- The potential profitability of informal irrigation, especially vegetable cultivation during the dry season.
- Allottees' desire to increase the size of their irrigated landholdings.
- For those not already possessing an irrigated landholding, the obvious attraction of exploiting a farm plot with access to irrigation water.
- The need to diversify cropping in response to market forces and the consequent search for soils better suited for the crops in question.

Strength and Composition of Farming Community

A survey conducted by IIMI in 1991 with the aid of the farmer Cooperative revealed that there were 339 farmers of whom 312 had allotments within the "official" command area and 89 outside it. Of this latter number, 62 had holdings within as well as outside the "official" command area.

About 50 percent of the allottees are from the village of Mogtédó itself while the rest of the allottees originate from 15 other villages located within a radius of 100 km. This highlights the heterogeneity of the farming community in the irrigation scheme as a result of migration into Mogtédó.

All allottees are men with the exception of two women (who happen to be widows). This maybe explained by the fact that the land allocations were made to the heads of households, generally men. A certain number of village groups also benefited from the allocation of irrigated plots.

From the socio-professional standpoint, the majority of the beneficiaries are full-time farmers. Among the remainder are local businessmen and even some public servants working for state agencies providing support services to the scheme.

ANALYSIS OF WATER AVAILABILITY

The Mogtédó Reservoir not only supplies water to the irrigation system downstream but also caters to domestic and livestock needs. In addition, water is pumped directly out of the reservoir for informal irrigation around its fringes. In the latter half of the dry season, even parts of the reservoir bed and its inner slopes are cultivated! This practice, which has assumed considerable importance in recent times, tends to accelerate the sedimentation of the reservoir and increase the risk of pollution from pesticides and herbicides; water released from the reservoir is also used for drinking purposes.

A technical note on the construction of the reservoir (SOGETHA 1964) and all relevant documents available at the time showed the storage capacity of the reservoir as 2.9 million m³. In

the course of its research, IIMI discovered an anomaly in the existing altitude-surface area-capacity curves of the reservoir. Computations based on the available information led IIMI to suspect that the reservoir capacity was at least two-and-a-half times the generally accepted value. The subsequent field survey commissioned by the Ganzourgou Province Rural Development Project (PDRG) confirmed that the reservoir capacity was, in fact, 6.5 million m³.

Figure 3.7 shows altitude-surface area curves as well as different altitude-capacity curves for the reservoir: (1) altitude-capacity curve shown in existing technical documents, (2) altitude-capacity curve reconstituted by IIMI in 1991 from existing altitude-area curve, and (3) altitude-capacity curve established after field survey in 1992.

It, therefore, appears that the water resource availability is greater than the initial assumptions which formed the basis of the design of the irrigation system. In theory, this situation opens up the possibility of further expansion of irrigated area. But an important precondition is the definition of a rational development strategy for the whole zone which also takes into account the integration of the "unauthorized" irrigated areas as well.

The irrigation scheme was designed for double-cropping of rice. Indeed, a study of very early project documents related to the scheme reveals that three development options were considered initially, two of which involved the development of approximately 120 ha on the left bank area. The final choice to limit the irrigated area to 57 ha was largely dictated by financial considerations. Considerable extents of land suitable for rice cultivation (within the system) or diversified crops (just outside the system) were thereby excluded from the "official" command area. It was on these very same lands that spontaneous, informal extensions originated. The fact that the reservoir was able to sustain this unauthorized extension may be attributed to its greater-than-assumed storage capacity. But the irrigation network, whose carrying capacity was not designed to serve this expanded area, cannot be overloaded beyond its present limit. Unfortunately, any attempts to reorganize water distribution making use of the existing canal infrastructure are rendered difficult due to the attitudes, influence and social status of most of the farmers resorting to informal irrigation.

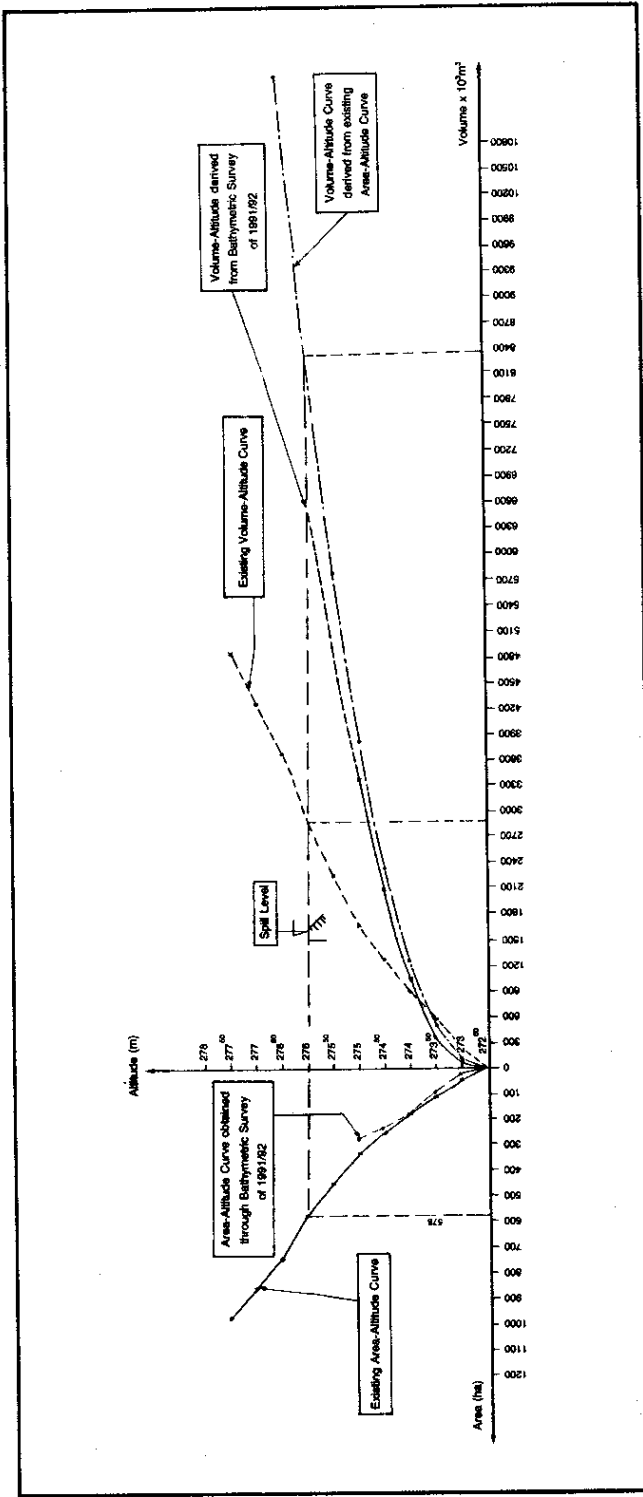
SOME ELEMENTS OF HYDRAULIC PERFORMANCE

According to the original design, the main canal and all the secondary canals were expected to run continuously during the daytime. Water was supposed to be distributed among the tertiary canals within a secondary block on a rotational basis. However, unauthorized extraction of water by pumping or siphoning from the main or secondary canals prevents the implementation of any operational plan. These "spontaneous irrigators" aggravate the "normal" deterioration of the system after nearly 25 years of existence by their attempts to gain access to water by (a) fabricating supplementary tertiary canals, (b) modifying or damaging the canal network, and (c) constructing temporary stone or brushwood weirs to raise water surface elevations and facilitate the operation of siphons.

It is difficult to accurately quantify the extent of unauthorized irrigation due to the rapid evolution of this phenomenon. The first attempt at assessing it was an extensive topographical survey carried out by IIMI in 1991 which revealed nearly 30 ha of unauthorized irrigation (Figure 3.6) and more than 70 points of unauthorized extraction of irrigation water. An inventory of nearly 40 diesel pumps which operate along the main canal was also established (Table 3.3).

It is important to note the existence of more than 10 pumps with a discharge capacity of around 15 l/s in the head reach. If all of them functioned simultaneously, nearly all the flow in the main canal would be intercepted, at the expense of downstream users.

Figure 3.7. Altitude-Capacity curves for Mogtédo Reservoir.



1. Altitude-Capacity curve shown in existing technical documents
2. Altitude-Capacity curve reconstituted by IIMI in 1991 from existing Altitude-Area curve
3. Altitude-Capacity curve established after field survey in 1992

Table 3.3. Inventory of pumps functioning along the Mogtédo Left Bank main canal.

Location on the main canal	Make of pump	Number	Nominal discharge (l/s)
Head reach	YANMAR	6	8 to 16
	TOMOS	7	8
	SUZUKI	2	16
	HONDA	3	8 to 18
	BERNARD-MOTEUR	2	8 to 16
Reach S1-S2	YANMAR	4	16
	SUZUKI	1	16
	HONDA	1	—
	BERNARD-MOTEUR	1	—
Reach S2-S3	YANMAR	2	16
	SUZUKI	2	16
	YAMAHA	2	—
Reach S3-S4	—	1	—
Reach S4-S5	YAMAHA	1	—
Reach S5-S6	YANMAR	1	—

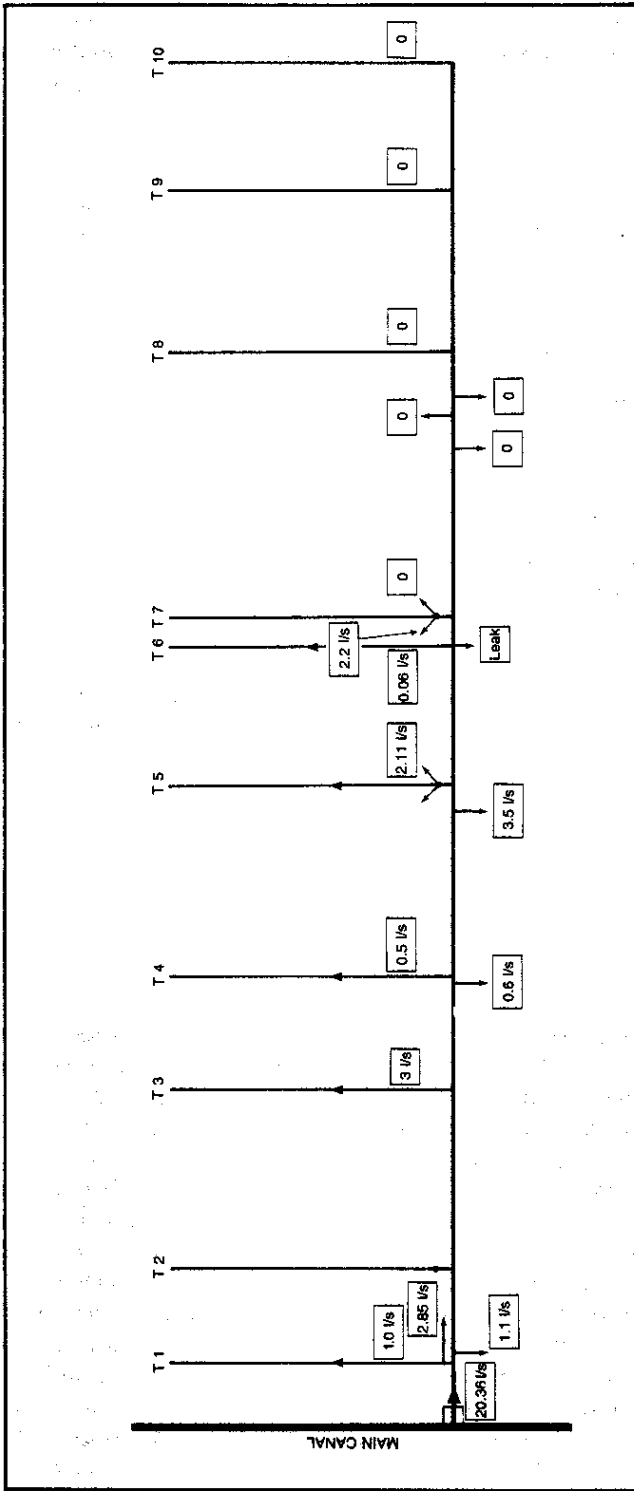
As a partial response to the advent of “spontaneous irrigators,” mainly along the banks of the head reach of the primary canal, the Cooperative introduced rotations among the secondary canals in the dry season as follows:

- Monday and Thursday : Secondary canals S1, S2, S3
- Tuesday and Friday : Secondary canals S4, S5, S6
- Wednesday and Saturday : Extension
- Sunday : No irrigation

The farmers of the “unauthorized” plots are expected to respect the same rotational plan as those of the secondary canals located nearby. This plan, having been established without any technical basis, is not compatible with the existing canal regulation structures (static weirs) which had been designed to function under totally different hydraulic conditions (continuous flow). In addition to the difficulty of controlling the unauthorized extraction of water, the twice-weekly local market and various other social events also tend to disorganize the operation of the rotational plan.

During the rainy season, the main canal flows continuously. The farmers are expected to organize the water distribution within the secondary and tertiary blocks. Secondary canal flows generally vary from 15 to 20 l/s (compared to their design capacity of 30 l/s). Practically all the tertiary canals along a given secondary canal function at the same time and, in addition, farmers tend to irrigate more than one plot at a time within tertiary blocks. Flow measurements indicate that tertiary canal discharges rarely exceed 5 l/s. One such example is shown in Figure 3.8, indicating the distribution of water flow along secondary canal S1. Such low flows lead to an increase in irrigation duration — 8 to 10 hours to irrigate a plot of 0.25 ha. Water distribution performance is further affected by the fact that farmers usually pursue other occupations (notably

Figure 3.8. Distribution of water flow along Secondary Canal S1 between 0915 and 1155 on 22 October 1991.



rain-fed farming in the wet season). They are thus unable to be present throughout the day to supervise the irrigation of their plots. This task is sometimes entrusted to a child who is unlikely to be in a position to respond to the caprices of farmers located further upstream concerning access to water.

Integration of "Spontaneous Irrigators"

Any proposal for improving performance in the Mogtédó Irrigation Scheme should necessarily address the question of how to integrate the "spontaneous irrigators" (this term, less pejorative, is preferred to the term "pirates") into the mainstream of system management. One alternative studied by IIMI (Keita 1991) relates to the integration of the informally irrigated areas on either side of the first 800 m stretch of main canal, located between the main sluice and the first secondary canal. Currently, water is extracted directly from the main canal via pumps or siphons. It is envisaged that the informal plots be grouped into a fixed number of irrigation units in order to limit the points of direct extraction along the main canal and thereby enable better means of control and potentially less disruption to water distribution. For example, IIMI has studied the possibility of constructing six new secondary canals on the head reach of the main canal, three of them serving informal plots on its left bank and three serving the right-bank plots. The canals may be supplied via a "collective" pump; tertiary canals can thereafter deliver water to the farm plots by gravity, pumping or siphoning according to the prevailing local topographic conditions. The proposed canal capacities are 15 l/s each and night irrigation becomes necessary. Another alternative considered is the construction of an independent main canal to serve the plots of the "spontaneous irrigators."

AGRICULTURAL PRODUCTION

Traditional Production System and Rain-Fed Farming

Before the creation of the irrigation scheme in 1967-68, Mogtédó was a small, sparsely populated village of less than 500 people. Rain-fed agriculture (rice cultivation in valley bottoms, and millet, sorghum, maize, groundnut elsewhere) constituted the principal activity, sometimes supplemented by livestock farming. Hardly any fertilizer (neither organic nor mineral) was applied to the fields; the main method of restoring soil fertility was to periodically leave land fallow by moving to other land in the neighborhood.

The migration which followed the construction of the reservoir and the Mogtédó Irrigation Scheme increased the pressure on arable land. Itinerant agriculture gradually gave way to a more settled type of rain-fed farming. At the same time, the use of improved varieties, modest application of chemical and organic fertilizer, and the use of animal traction found their way into the rain-fed agricultural practices. However, productivity remained low, mainly due to the combination of unfavorable climatic conditions, poor quality soils, and a socioeconomic context which did not allow a higher level of intensification.

In the small irrigation schemes such as Mogtédó, irrigated agriculture has to be supplemented with rain-fed farming and/or other off-farm activities. The returns from irrigated agriculture do not permit the farmer to abandon rain-fed agriculture which, in addition, is a more deep-rooted rural tradition. A recent study (Projet Sensibilisation 1991) conducted on an irrigation scheme in the northeast of the country revealed that irrigated agriculture only accounted for around 6 percent

of the annual family revenue, during a year when rainfall was better than normal (in drought years, it may be expected to contribute a higher percentage). Due to their relatively small size (0.15-0.30 ha), the total production from an irrigated landholding remains low, compared to that from rain-fed plots which are 3-5 ha in size; however, productivity (3,000-4,000 kg/ha) is very high compared to the 700-800 kg/ha from rain-fed farming. Moreover, rice, the principal irrigated crop, unlike millet or sorghum from the rain-fed farms, does not form part of the traditional rural menu and is considered as a commercial crop or is reserved for special occasions.

In the farmers' decision-making process and evaluation of risk, rain-fed farming takes first priority due to its dependence on unpredictable rainfall. A delay in commencing the irrigation season is considered less risky on account of the security offered by the storage reservoir (unless, of course, the season extends into December and January when the cold weather could cause reduction in yields). The lack of sufficient manpower to enable the simultaneous pursuit of rain-fed and irrigated farming is yet another constraint. All these factors tend to have an adverse effect on irrigation system performance. Besides the fact that optimum use is not made of rainfall, all phases of the cropping calendar, from land preparation through replanting to harvesting get delayed, resulting in the depletion of the water stored in the reservoir at the end of the rainy season. This, in turn, diminishes the extent of cultivation possible in the dry season (and hence cropping intensity).

Irrigated Agriculture in the Rainy Season

As stated above, the principal irrigated crop is rice. A large number of rice varieties are in use in the Mogtédó Irrigation Scheme of which the most popular are IR 1529 and IET 2885. The Gambiaka variety is appreciated mostly by farmers having landholdings in low-lying areas. However, variety 4456, currently recommended by the national agronomic research institute, is hardly cultivated by the Mogtédó farmers (see Table 3.4). Only a small minority of farmers use certified seed, the majority producing their own seed rice.

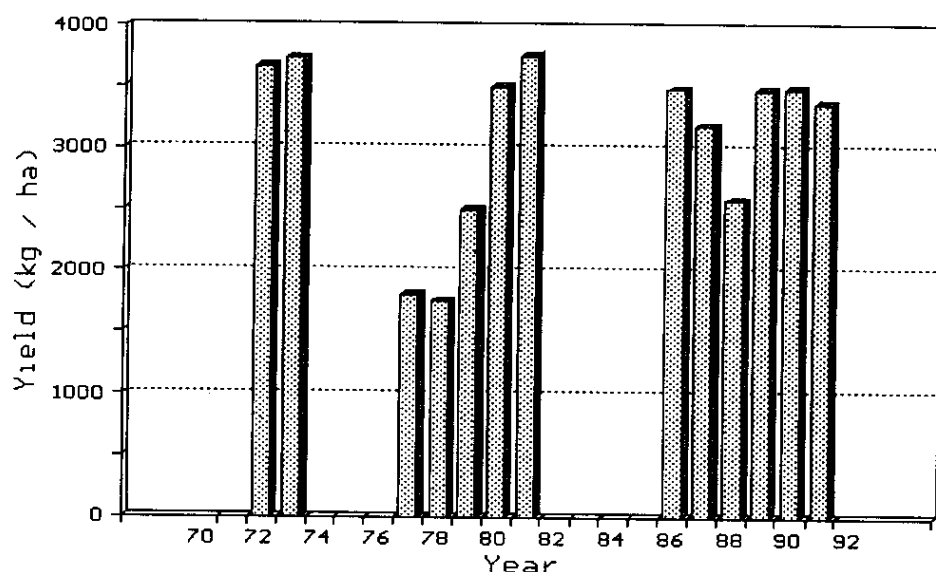
Table 3.4. Distribution of rice varieties and yields in Mogtédó in the wet seasons, 1991 and 1992.

Variety	1990			1991		
	Percentage of total area	Yield (kg/ha)	Total production (kg)	Percentage of total area	Yield (kg/ha)	Total production (kg)
IR 1529	76.4	3,797	279,573	58.7	3,533	198,504
IET 2885	16.8	3,296	53,626	32.0	4,169	127,742
GAMBIAKA	4.7	1,965	8,882	3.8	2,481	9,156
TOX 728-1	1.2	4,183	4,685	4.0	3,987	15,189
4456	0.9	3,589	3,155	1.5	3,464	4,954
Total (all varieties)	100.0	3,366	349,921	100.0	3,527	355,545

The average yield (for all varieties) of approximately 3.5 t/ha is low when compared to the potential. The highest yielding varieties are Tox and IET 2885 (≈ 4 t/ha), whereas Gambiaka

produces the lowest yield (≈ 2 t/ha). Figure 3.9 shows the rice yields in Mogtédo for some years during 1972–92, based on available records. Among the reasons for the relatively low and unstable yields recorded are acidity of the soils, imperfect land leveling, inadequate attention to weeding, and incorrect application of fertilizer. Some uncertainty also arises out of the method used to estimate yields — weight of unhusked rice (based on the number of 80-kg bags declared to the Cooperative) divided by the area cultivated — because farmers do not declare their entire harvest to the Cooperative.

Figure 3.9. Rice yields in Mogtédo (data available, 1972–92).



With regard to the cropping calendar, nurseries are established quite late and extend over a long period (early June to late July), due largely to the competition from rain-fed agriculture. The size of the nurseries is smaller than accepted norms; the nursery area to farm area ratio is of the order of 1 percent on average, compared to the recommended value of 3 percent. Thus the number of plants available is often insufficient to plant the whole plot and some farmers are obliged to create a second nursery. This results in crops at different stages of maturity coexisting within a given plot. Replanting also extends over a long period, as shown in Figure 3.10, which depicts the progress of replanting of the rice crop in the rainy season, 1991, which extended to over two months.

DRY SEASON CROPPING

It is difficult to obtain accurate information on the spatial and temporal distribution of dry-season crops in Mogtédo, due to the significant extents of land cultivated outside the “official” command area. IIMI’s best estimate of the total area of diversified crops (within and outside the “official” command) in the dry season, 1991–92, is 43 ha, distributed as indicated in Table 3.5. In addition,

Figure 3.10. Mogtédo: Progress of replanting the rice crop, wet season, 1991.

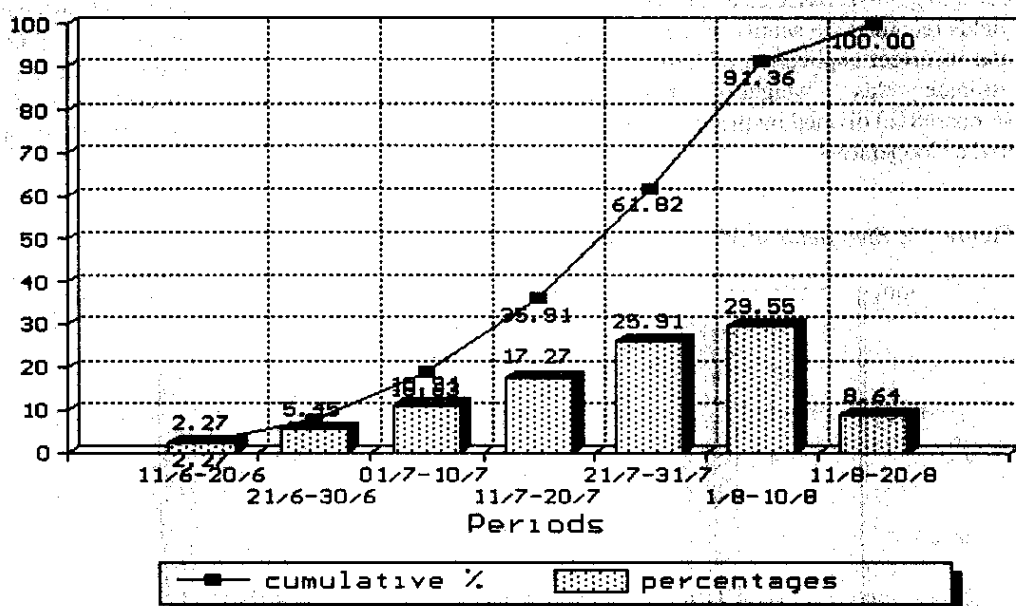


Table 3.5. Distribution of crops other than rice in Mogtédo, dry season, 1991/92.

Crop	Area cultivated (ha)		
	"Official"	Informal	Total
Onion	2.7	11.1	13.8
Tomato	4.5	6.7	11.2
Egg-plant	2.3	7.0	9.3
Others	2.5	6.0	8.5
Total	12.0	30.8	42.8

there was significant rice cultivation (generally confined to the "official" command area), estimated to cover nearly 30 ha.

Of the crops other than rice, onion was, in general, the most extensively cultivated variety. Tomato cultivation took precedence on the heavier soils which are less favorable to the development of onion bulbs.

It is noteworthy that more cropping has occurred outside the "official" command area than within. One argument made by the farmers in support of this practice is that there is a high incidence of still unidentified pest attacks within the "official" command area.

Another remarkable feature this year has been the large extent of rice cultivation during the dry season, even on the nonhydromorphic soils. This phenomenon may be explained in part by the significantly greater water resource available in the reservoir this time compared to the previous dry season. Investigations are underway to understand the real motivations of farmers to grow rice in the dry season. If water was not a constraint, would farmers prefer to grow rice, even during the dry season? Or, is it because of the possibility of growing other crops outside the "official" command area?

The area occupied by each crop on a given parcel is small (0.01 to 0.18 ha) but as there is generally an association of different crops within a given parcel, each farmer finally cultivates a total area comparable to that of rice in the wet season (0.20 to 0.44 ha).

The quality and origin of the seed used are unknown. Some farmers produce their own onion and tomato seeds. Accurate information on yields is not available as the Cooperative is not involved in marketing the produce (vegetables as well as rice), unlike in the case of the wet season. The intensity of the extension and support services is less than in the wet season but this does not appear to seriously handicap farmers' performance. On the contrary, their remarkable capacity to adapt and innovate appears to yield (at least for some of them) high returns, as demonstrated by their ability to invest in pumping and siphoning equipment.

As in the case of rice cultivation, the crop calendar extends over a long period of time; for example, nursery preparation stretches from October right through to January or February. Harvesting gets delayed till May or June, and enters into conflict with planting activities in the rain-fed lands at the start of the rainy season. The end result is yet another delayed start to the next rice cultivation season.

SOCIAL ORGANIZATION OF THE IRRIGATION SCHEME

In this section, the objectives and strategies of the principal actors within the system are analyzed with a view to understanding the social and organizational dynamics of the scheme. The distribution of power and authority and the nature of the interactions (affinity, opposition, etc.) among the actors are highlighted.

Management Committee

The composition and responsibilities of the committee have already been described in the section on the organizational structure. Unfortunately, it does not appear to have functioned in a particularly consistent manner — at times it has acted rather hesitantly while at other times it has acted very vigorously. But on the whole, it has been a forum for endorsing the decisions made by the Board of Directors of the Cooperative. Members meet occasionally at the request of the Board or assemble for semiannual general meetings of the Cooperative. In effect, the Management Committee does not seem to have fulfilled the roles expected of it in the legislation. Otherwise, the illegal expansion of the irrigated area may not have continued to the point where it is today.

Board of Directors of the Cooperative

The Board of Directors of the Cooperative is composed of its President, Vice President, Secretary, Treasurer, Assistant Treasurer and 3 other farmers. The Board appears to function as an oligarchy, capitalizing on the social and economic standing of its members, some of whom are politically influential as well. Based on interviews of some of its members, it came to light that the Board does not meet regularly but that instead, decisions are often made by a core group made up of the President, Secretary and the Treasurer.

The present Board, in office for the past two years, is nevertheless making a serious effort to redress the financial situation of the Cooperative resulting from the failures and errors of its predecessors. The Board also admits that it lacks technical expertise to effectively address questions related to water management and would welcome support in this field. On the other hand, reconciling the divergent interests in this area is difficult because, on the one hand, the Board is expected to exercise its authority to arbitrate conflicts and ensure that water management plans are respected, while on the other, it implicitly condones acts of water piracy.

The Gate Operator (*Aiguadier*)

The Gate Operator is one of the early settlers of Mogtêdo. He officially took over this position in 1982. Though he has not undergone any formal training, he has acquired some notions about system management through on-the-job experience. Being a farmer himself, he cultivates a number of parcels, both within and outside the "official" command area, in addition to his gate-operation duties. His main tasks are opening the main sluice every morning and closing it in the evening, and also adjusting the settings of the calibrated distributors along the main canal. He usually does not intervene at lower levels of the system. He maintains good relations with the farmers in general and constitutes a link between them, the extension agent and the Board.

The Extension Agent (*Encadreur*)

Another long-standing member of the Mogtêdo community, the *encadreur*, appears to have lost some of his technical credibility, and farmers believe that they have no need for further support from him. However, he remains particularly active in providing administrative assistance to the Board.

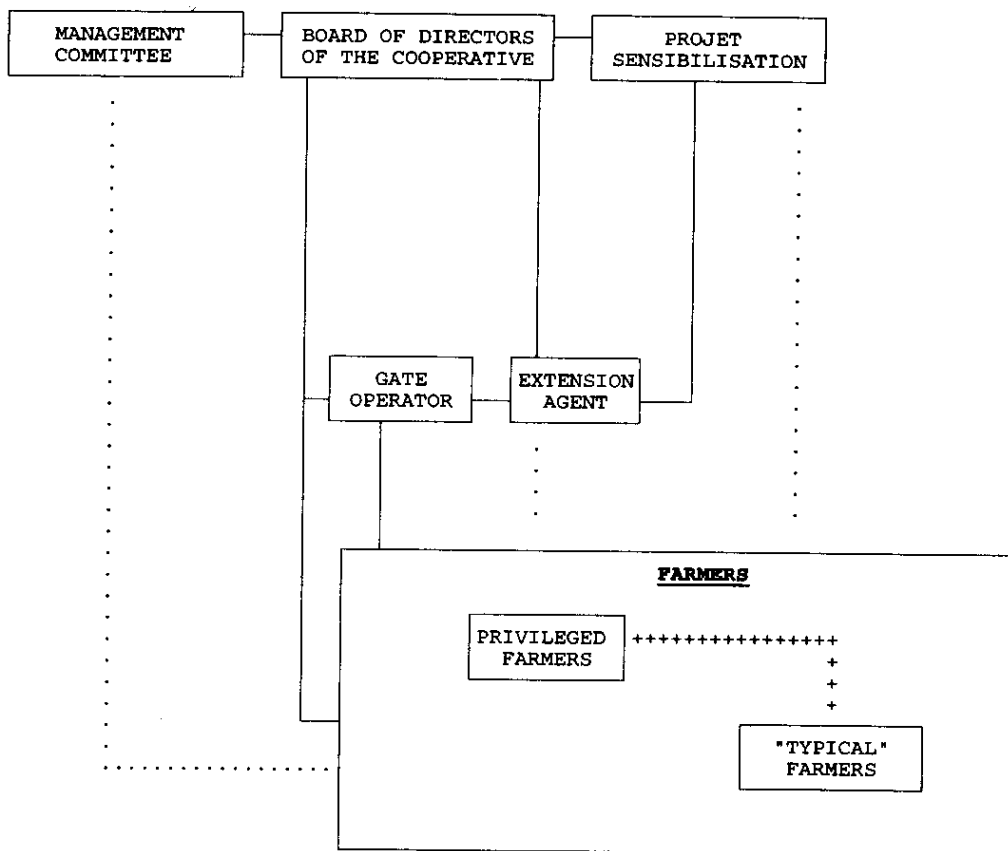
Farmers

The analysis in this instance is limited to two categories of farmers, namely, *privileged* farmers and *typical* farmers. Farmers belonging to the former category, though fewer in number (less than 20%), possess more than one parcel (within as well as aside the system) and enjoy a higher social and economic status. Nearly half of them possess pumps and the other half siphoning equipment for irrigating their "unauthorized" fields. As for the latter category, they generally pursue rain-fed farming in addition to irrigated farming. These farmers are the ones who suffer most as a result of the disruptive practices of the privileged farmers. They are often constrained to resort to irrigation

at night. Although they participate in collective activities, these farmers make little or no input to the decision-making process of the system.

The nature of the interrelationships which exist among the different actors in the irrigation scheme is represented schematically in Figure 3.11.

Figure 3.11. Sociogram of the Mogtédou Irrigation Scheme (schematic representation of relationships among the different actors).



Legend:

———— Collaborative relationship

..... Weak relationship

+++++ Conflicting relationship

INSTITUTIONAL AND LEGAL CONSIDERATIONS

Nearly 20 legal texts dealing with the organization and management of irrigation schemes in Burkina Faso have been drawn up at regular intervals since 1960. A priori, this relatively large

number of texts could be interpreted as a measure of the importance attached to rural development, in general, and irrigation in particular. However, in reality, the legal framework was long characterized by (a) the absence of applicable decrees in the case of legislation which had been adopted, (b) the nonfinalization of a number of other legal texts which had not proceeded beyond the draft stage, and (c) the limited dissemination and lack of information relating to rules and regulations actually in force.

This fluid situation naturally led to decision making, on the part of state institutions as well as farmer organizations, which bordered on the arbitrary without regard to the provisions and guidelines laid down in the legal texts. In effect, one may rightfully wonder whether most of the deviations observed in the Mogtéo Irrigation Scheme could well have been avoided if the Management Committee, the state support services and the farmer Cooperative had carried out their respective supervision and management responsibilities more effectively. For example, the different forms of support received by the Cooperative over the years should have enabled it to develop a sense of institutional maturity. However, it must be admitted that even after 25 years of existence, although referred to as a "Cooperative," the farmer organization does not conform to all the legal requirements normally associated with this status.

Recent attempts at reducing the confusion in the legal and institutional frameworks have led to the review and revision of the different legal texts. Following the most recent initiative in 1991, irrigation schemes are now considered to be governed by three general legal texts dealing respectively with (a) agrarian and land reform, (b) the cooperative sector, and (c) the operation and maintenance of irrigated land. In addition, a certain number of other laws dealing specifically with the organization and management of irrigation schemes in the country are also supposed to apply. Further work needs to be done to overcome omissions and contradictions that still exist and to harmonize these different legal texts. IIMI, as part of its research effort, will contribute to achieving this goal.

However, the capacity of the farmers, who are key actors in this domain, to develop skills in organization and management, and to communicate and exchange information effectively is seriously handicapped by low literacy levels and the nonavailability of the various legal texts in the vernacular. The running of the Cooperative remains the preserve of a privileged few. Even though performance from the organizational standpoint may appear to be weak, this has not been the case in assimilating the technical aspects of irrigated agriculture. In effect, farmers give the impression that they have little to gain from continued technical assistance on the part of the extension agents. This, in turn, raises questions regarding the credibility, competence and overall quality of the support services.

Although the farmers attitudes vis-à-vis irrigated agriculture have gradually evolved over time to the point where there is a strong interest in obtaining an irrigated plot, they display little enthusiasm for managing the scheme in a truly cooperative spirit. Ideally, the guiding principle should be based upon solidarity, with all the members acting together to achieve a common objective and for mutual benefit. This egalitarian viewpoint is, however, incompatible with the rules of traditional rural societies which are dominated by ties of kinship, feudalism, deference to elders, submission of women, etc. By and large, farmers prefer to avoid entering into conflict with tradition, thereby strengthening the hand of the traditional authorities to take over the embryonic cooperative movement. It is, therefore, evident that without any form of external control or audit, the technical, administrative and financial management of the organization will be difficult to reconcile with the objectivity and transparency necessary for effectively managing a modern agricultural enterprise.

The development of irrigation facilities requires heavy state investment, which in the end is a cost to the entire nation. Present estimates put the costs at more than 5 million CFA francs (US\$ 20,000) per hectare with total water control, not including the cost of the dam construction. The

state has a responsibility to continue to maintain a supervisory or regulatory role in the management of the irrigation scheme, and thereby ensure the sustainability of its investment. It is unreasonable that the national collectivity be ultimately called upon to bear the consequences of mismanagement on the part of an autonomous and supposedly responsible cooperative organization.

On the other hand, state law is often in conflict with customary land rights. The land tenure system, where the state expropriates and redistributes land within the irrigation system, and the relatively small size of the irrigated plots do not encourage the farmer to invest in and develop his allotment. The challenge is thus one of attempting to reconcile the rights of ownership of the state, as principal investor, with the need to offer some guarantee of medium-term or long-term tenancy to farmers (lease, contract, etc.) which would encourage them, in turn, to invest in improving the productivity of the land.

CONCLUSIONS

The Mogtéo Reservoir has been the nucleus of economic growth of the village and its neighborhood. But the development, largely triggered off by the initiative and innovative spirit of the local population, did not always follow a coherent plan. Uncontrolled expansion of the irrigated area within and around the scheme has today reached a point where it threatens the sustainability of the system. The physical infrastructure (irrigation and drainage canals, structures, spillway, etc.) is in urgent need of rehabilitation. Organizational and institutional weaknesses add to this perilous situation. On the other hand, the fact that the Mogtéo Irrigation Scheme has functioned for nearly 25 years without being rehabilitated amply demonstrates the farmers' capacity to adapt to situations and take the initiative to assume responsibilities when their own interests are at stake. This paper has attempted to identify the causes for this extraordinary situation.

The Cooperative does not appear to have succeeded in reconciling traditional social values with the principles of objectivity and transparency which should underpin the running of a modern agricultural enterprise. With little or no supervision on the part of the Management Committee, the Cooperative was taken over by personalities with social and political influence. Institutional weaknesses related to the dissemination of the relevant legal texts and enforcement of the rules have contributed to the inability, or unwillingness, of the authorities to exercise statutory control and supervision of the reservoir and the irrigation scheme.

Certain assumptions and information used in the initial design of the scheme have proved to be erroneous, such as the storage capacity of the Mogtéo Reservoir. This would account for the fact that the reservoir has been able to sustain the informal expansion of irrigated area to cover large extents of land suitable for rice cultivation (within the system), or diversified crops (just outside the system). These lands were initially excluded from the "official" command area due to financial constraints. Although the enhanced availability of the water resource theoretically opens up the possibility of further expansion of the irrigated area, the definition of a rational development strategy for the whole zone, which also takes into account the integration of the "unauthorized" irrigated areas already in existence, is an important precondition.

However, the existing canal network does not have the capacity to accommodate further extension of the command area. The canals and structures already have to cope with situations which they were not designed for. Water is either pumped or siphoned out of the main canal itself, to irrigate unauthorized extensions, to the detriment of water users further downstream. The theoretical operating rules no longer hold good. System operations result from the sum total of a number of individual operations rather than emanating from a coordinated collective strategy. Attempts to respond to the new situation making use of the existing physical infrastructure but

with different organizational arrangements have met with limited success because it is usually the most influential farmers who resort to "water piracy."

Personnel directly involved in system management (i.e., the extension agents or encadreurs) focus primarily on agronomic inputs. This attitude is partly due to their lack of training and skills in irrigation water management. Main system operations, in particular, are left to a farmer who also acts as a part-time gate operator.

Although farmers appear to assimilate technical issues quickly, they find it more difficult to reconcile the philosophy of the cooperative movement with traditional hierarchical rules governing rural society. Power and authority within the farmer organization tend to rest with a privileged minority, not entirely convinced by the merits of "democratization." Serious efforts need to be deployed to impart basic management and administrative skills to the farmers to prepare them to effectively take over the management of their irrigation system. One fundamental question that needs to be addressed is what role the state should play, if any, in supervising, regulating, and indeed strengthening farmers' management capabilities and ensuring that the process of management turnover does not threaten the sustained well-being of the irrigation scheme.

The existing system of land allocation and tenure is not conducive to improving irrigation performance. The introduction of appropriate measures to encourage farmers to invest in improving the productivity of the land demands a lot of political courage to reconcile state ideology with farmer logic.

The understanding and knowledge generated through the sociotechnical diagnosis of irrigation schemes undertaken by IIMI and its national partners will contribute to the creation of an appropriate technical, organizational, institutional and legal environment to develop and sustain improved irrigation performance.

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CHAPTER 4

Impacts of Physical and Managerial Interventions on Canal Performance in Pakistan: A Review of Five Years of Field Research Studies

***Edward J. Vander Velde
and
D. Hammond Murray-Rust***

INTRODUCTION

THE OBJECTIVE OF this paper is to review the results obtained from a set of related research activities that assessed the impacts of physical and management interventions in various distributary canals in the Lower Chenab Canal (LCC) system, Punjab, Pakistan, over the past five years (Vander Velde 1991, Bhutta and Vander Velde 1992). The locations of these various research sites are shown in Figure 4.1.

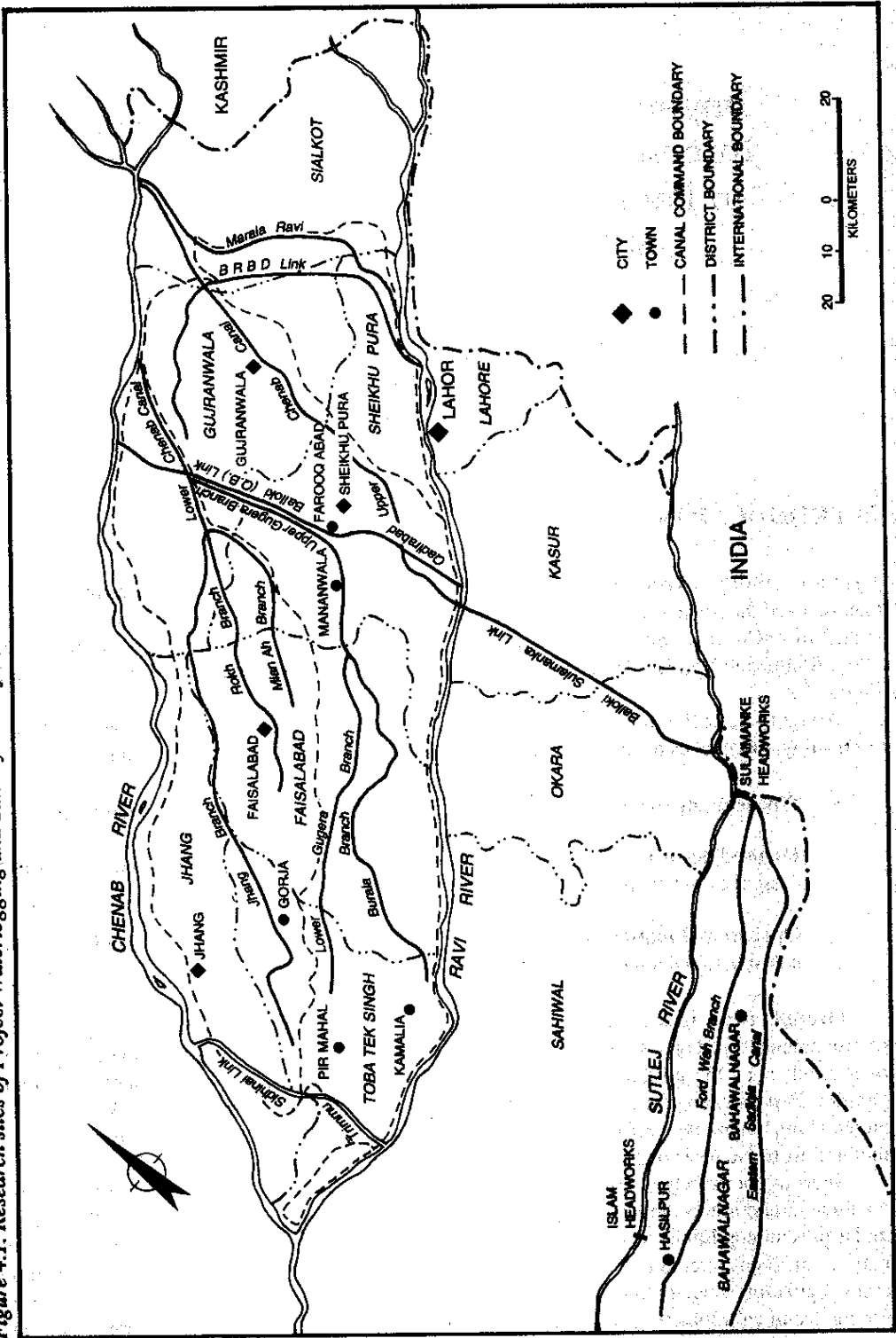
A key facet of the research in the LCC system reviewed here is that a comparison of three contrasting approaches to secondary canal performance improvement is now possible:

- **Physical improvement** of the conveyance system, primarily through canal lining.
- **Focused desilting** of existing canal infrastructure that aims to restore, as far as possible, designed conveyance conditions.
- **Operational management** to ensure that available water is distributed as efficiently as possible to meet the stated operational objectives of irrigation agencies.

Overall, there is a significant opportunity to go beyond studies that simply describe improvements based on a single intervention but do not address the relative merit of one approach over another, or the possible synergistic impact of undertaking two or more interventions in parallel. Furthermore, the findings justify making some specific recommendations for policies aimed at improving the performance of canal systems in Pakistan. Definition of a set of activities that will form the basis of practical options for irrigation managers is also possible.

Short of completely overhauling the canal system in Pakistan, an impossibly expensive task, the three interventions identified above represent the only realistic approaches that can be adopted under present conditions to improve the performance of the secondary canal system. There will be different interventions possible in the main canal system, including provision of more cross-regulation capacity than that currently exists, but to date IIMI has had neither the resources nor the technical capacity to undertake studies in this portion of the irrigation system in Pakistan.

Figure 4.1. Research sites of Project Waterlogging and Salinity in Punjab, Pakistan.



Finally, before proceeding further, it may be appropriate to strike a cautionary note. Despite the relative success of this work as a research program, both as an example of how to conduct such research and in transforming results into practical options for irrigation agencies, institutional conditions in Pakistan simply do not yet favor a performance-oriented approach to irrigation management. Concerns with personal advancement frequently outweigh rational use of resources for either construction or maintenance; moreover, both the increasing frequency of political interference in canal systems and the declining law and order situation over much of the rural countryside makes it hard for irrigation-agency staff to implement operational plans effectively.

ESTABLISHMENT OF THE CANAL RESEARCH PROGRAM

In common with the experiences of other field offices, IIMI-Pakistan initially found it difficult to clearly identify research issues that were both feasible and of interest to line agency staff. This was partly a consequence of the relatively low level of resources and facilities available when the office was established, and partly because IIMI came to Pakistan with no proven track record. It is not unreasonable to expect a country to be cautious in opening its offices, data records and irrigation systems to researchers from an unknown institution.

An additional impediment was posed by prevailing conventional wisdom. In the early discussions on nearly every possible research topic, agency staff were convinced they not only knew the true nature of things at field level, but also believed that canal systems in Punjab were really performing quite well. Under such conditions, it was difficult to obtain concurrence with research proposals to undertake field studies, which implicitly questioned this conventional wisdom.

One notable bias among irrigation agency staff was that studies of canal operations were unlikely to be particularly useful. It was repeatedly stated that the main and secondary canal system in Pakistan provided little opportunity for management intervention since canals were run more or less at full supply level for eleven months of the year. Because actual discharges were believed to be always at, near or even above actual designed discharges, it was assumed there was no further flexibility in the system that could form the focus for managerial interventions. While observations during the first field trips (and on the daily drive to work along Lahore Branch Canal) indicated that water levels did (and do) fluctuate, and over a significant range during quite short time periods, no window of opportunity soon appeared for initiating a structured research program.

Whenever interest was expressed by staff of various provincial or federal irrigation, agriculture and water resource agencies, it commonly was oriented to tertiary and farm-level issues. This partially was a reflection of the high public profile of the On-Farm Water Management Program in Pakistan, with IIMI being perceived as having a role not dissimilar to that played by other foreign research consultants in the past. But, it also served to perpetuate the myth that the problems of irrigated agriculture in Pakistan basically are a consequence of farmer ignorance. It has long been the ethic of agency staff to place the blame for the comparatively poor performance of irrigated agriculture at the door of farmers, and to advocate training and organizational activities as the solution to problems of farmer inefficiency and low production.

Interest in Canal Lining

The first opportunity to undertake research in the main and secondary canal system finally emerged when the Punjab Irrigation Department (PID) asked whether IIMI would be interested in

undertaking an evaluation of the benefits of canal lining in two canals near Lahore. The provincial irrigation departments had watched with some envy the substantial flow of resources into the watercourse lining component of the On-Farm Water Management Program that had been managed through provincial agriculture departments. There was also some professional pique that agriculturalists were involved in irrigation-related lining programs, albeit at the watercourse level. Although substantial resources to improve canal-system infrastructure had been made available to the irrigation departments through the World Bank/USAID co-financed Irrigation System Rehabilitation Project (ISRP), there was strong PID interest in developing a wider lining program in secondary and minor canals. While this first research activity was comparatively modest, it was to provide the basis for a sustained and increasingly complex research focus on the assessment of canal performance in Pakistan.

The two canals in question, Lagar and Ghordaur distributaries, offtake from Upper Gugera Branch of the LCC system. They had been selected for the PID's lining experiment because they were "problem" channels, the "problem" being that water supplies at the tails were well below design and had been so for extended periods. It was hoped that lining would make it possible to get more water to the tails and thereby reduce or eliminate the continuing complaints of farmers in tail watercourses about the lack of surface water. Lagar and Ghordaur distributaries also proved to be conveniently located for inclusion in IIMI's research program; they were readily accessible from Lahore during the initial stages of establishment of IIMI-Pakistan, and were within easy distance of the first IIMI Field Station being established at Farooqabad in Sheikhupura District. In retrospect, it is hard to conceive a more suitable starting location for the research program.

The Lessons of Lagar and Ghordaur Distributaries

As reported in the first *IIMI Review*, the results of this first study were inconclusive (Murray-Rust 1987). The only data sets available were secondary information from the PID's subdivisional records, consisting of water level data at the head of each canal and water levels at the tail gauges. Both sets comprised data reputedly measured and collected on a daily basis. However, it was impossible to realistically assess the impact of lining on subsequent canal performance because there were considerable doubts about the veracity of the tail gauge data, and because there had been a major increase in actual discharges into both canals following lining.

Despite the inconclusiveness of that first study, several important lessons were learned in relation to design and implementation of subsequent research activities. They include the following:

- **Data available from official sources could not be used as a basis for intensive research studies.**

Data from agency records are patchy, often inaccurate and insufficiently documented to form the basis for research. In some cases, they may be indicative of actual conditions, but they should not form the basis for detailed research studies unless they can be verified through parallel field measurement programs.

- **Physical and hydraulic conditions along distributaries appeared to deteriorate about two-thirds down the channel.**

The field observations made along both Lagar and Ghordaur suggested that water conditions in the upper half of the secondary canal were reasonably good, but that

somewhere after about half way down the channel, discharges became inadequate even though discharge at the head was at or close to the designed value. This observation could not be substantiated initially by available data, but clearly lining could not be effective if there were inadequate water conditions upstream of the lined section.

- **Canal operations greatly influence canal performance in both lined and unlined conditions.**

The PID data clearly indicated that there were fluctuations in discharge into secondary canals resulting both from water level fluctuations in the main canal and operation of secondary canal head gates. This finding contrasted sharply with the conventional view that there was little or no opportunity for management in the main and secondary canal system.

As a consequence of these findings, field-based activities on a number of topics were added to the emerging research program. There were:

- ***Continued interest in performance resulting from canal lining***

It was agreed to continue research into the impact of lining, but only where it could be conducted in more controlled conditions: a baseline study of water supply conditions prior to intervention, and a similar set of readings once the intervention had occurred.

- ***Studies on changes in hydraulic performance along canals***

The apparent deterioration in hydraulic performance resulting in major differences in water distribution equity between head and tail watercourses even when discharges into the canals were at or close to designed levels provided a significant research opportunity to examine how these canals actually function, and what could be done to address the obvious conditions of inequity.

- ***Studies on the operation of secondary canal head gates***

In an environment where the number of locations for management intervention are limited, it is obvious that the level of management applied at these locations must be of high quality. Frequent fluctuations in discharges into secondary canals, and evidence of extended periods of operation at discharges well below design limits presented opportunities for operational improvements, but required more data before recommendations could be developed.

Although the results of each of these three activities are reported separately here for purposes of clarity, in reality, there was considerable complementarity and linkage in implementation of the components of the research program and the subsequent reporting of results.

Finally, in this first stage of research, one overall guiding principle was adopted:

Before rushing in with action-research programs that might only yield ephemeral improvements, it was necessary to first have a clear description and understanding of current levels of canal performance, and to then try to deduce what would be the most effective management strategies that could be adopted on a lasting basis by irrigation agencies.

THE IMPACT OF LINING ON CANAL PERFORMANCE: KHIKHI DISTRIBUTARY

IIMI's research had already established that official records of water conditions were inadequate below the head of secondary canals, although they were reasonably reliable for many locations along the main system. Therefore, undertaking a reliable and scientific evaluation of the impact of lining on canal performance would require a long-term commitment to repeated measurements under controlled or known conditions at many locations along a distributary.

Surprisingly enough, selecting a suitable site for such a study proved remarkably difficult. Although several minor distributary canals were being lined through the Command Water Management Project, no data of sufficient quality were available for the before-lining condition or, in most cases, for conditions following improvement.⁶ From the perspective of research, the data environment was no better than the conditions encountered in Lagar or Ghordaur. A few other canals were lined during 1988 but either because IIMI did not have enough lead time to undertake the pre-lining survey or because the locations were too difficult to access from existing research sites, none of these canals could be included.

Eventually an opportunity arose at Khikhi Distributary. This canal is located in the Lower Gugera Division of the Lower Chenab Canal. IIMI had for some time been interested in working in the tail-end portion of a major canal to provide a contrast with upper-end conditions studied in the Farooqabad area, and Khikhi provided sufficient interest for IIMI to establish a second field station in Bhagat Subdivision. In addition, it removed some criticism IIMI had encountered for working only in small canals: Ghordaur has a design discharge of $1.4 \text{ m}^3/\text{sec}$, Lagar only $1.1 \text{ m}^3/\text{sec}$, while Khikhi has a design discharge of almost $10 \text{ m}^3/\text{sec}$ and irrigates some 42,000 ha.

Khikhi Distributary was well-known as a "problem canal" with chronic and long-standing water shortages at the tail end. In addition, Khikhi supplies drinking water to several areas where the groundwater is of unsuitable quality for human consumption. These problems were of sufficient magnitude that they aroused the attention of the late President of Pakistan, General Zia. In response to complaints, he eventually sanctioned the use of special Presidential Funds to be released to the Irrigation Department to undertake various remedial measures.

On receipt of these funds the Punjab Irrigation Department developed a two-stage strategy. The first activity involved a program of desilting, in 1986, using mechanical and manual inputs to clean out much of the upper two thirds of the distributary. The second activity involved lining, but this could not be started immediately due to the time required for developing detailed designs and submitting the final estimates for approval.

The delay in actually implementing the lining program enabled IIMI to undertake a complete baseline survey of hydraulic performance along Khikhi Distributary in the period between desilting and the commencement of lining. As it turned out, the lining program itself extended over a three-year period in order, it was stated, to minimize disruption in irrigation supplies to farmers. Because work was divided into several phases, with construction proceeding slowly upstream from the tail, IIMI was able to undertake a further three sets of readings over the first two stages of lining. The last phase of lining was completed in late 1990, and a final set of measurements were taken in late 1992 to complete this study. These readings had been deliberately delayed in order to make sure the hydraulic conditions at the head of Khikhi would be essentially the same as those for previous measurement sets.

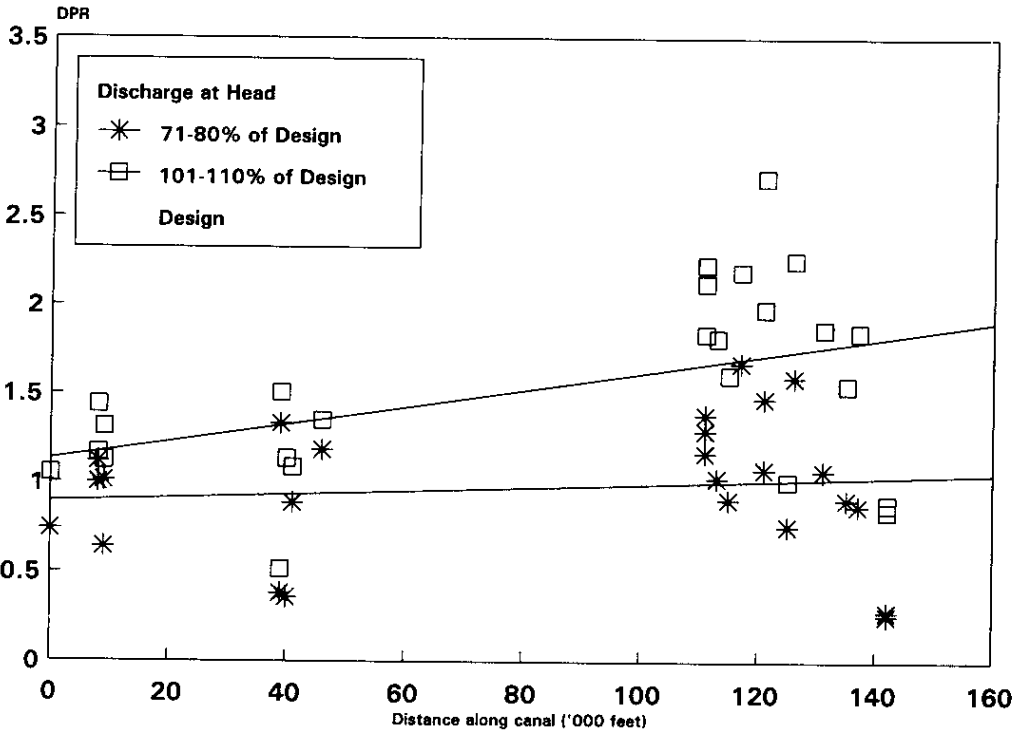
⁶ Given the magnitude of the costs associated with these lining activities, it is disturbing that such financial decisions continue to be made without a careful examination of pre-lining conditions, an assessment of the likely benefits to accrue from such an intervention and a rigorous evaluation of the results actually achieved.

The main results of the research can be summarized as follows:

- **Tail-end water conditions did not improve following the desilting of the canals**

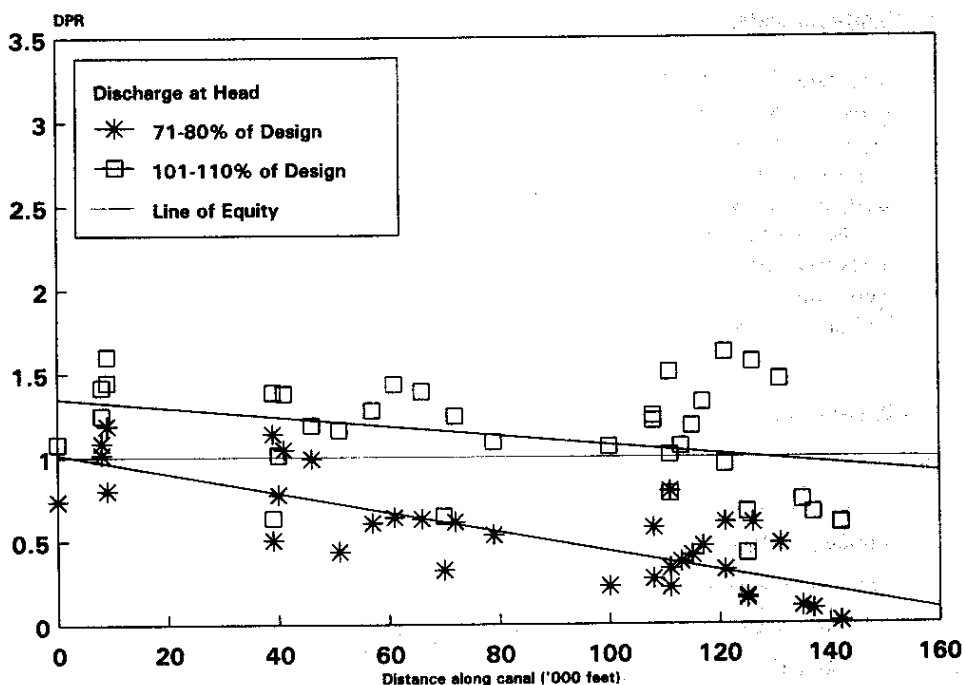
The data show no significant change in water conditions at the tail end of the canal between the different measurement periods. The immediate reason for this is quite obvious: the desilting, taken as a contingency measure prior to lining, appears to have improved things so much that the Delivery Performance Ratio (DPR) in tail-end watercourses was not significantly different from those at the head. At high discharge levels, for example, the DPR of tail-end watercourses was better than those in head-end areas and more or less the same along the distributary when discharges into head of Khikhi were about 75 percent of design (Figure 4.2). Consequently, there was little room for hydraulic improvement as a result of the lining.

Figure 4.2. DPR, Khikhi Distributary, after desilting, before lining.



To make matters worse, there is evidence that tail-end water conditions have declined since the onset of the lining program. Examination of the conditions prior to the penultimate phase of lining show that tail-end areas only receive their fair share when the discharge is above design at Khikhi head, and the conditions deteriorate rapidly when discharges drop below design (Figure 4.3).

Figure 4.3. DPR, Khikhi Distributary, after lining.



- Volume of water delivered to the tail has not increased.

Although the lining of Khikhi was not explicitly intended to save water, lining is frequently promoted as one way of saving water. Using data from sample watercourses only, it is difficult to be definitive about water savings. However, the average DPR of the sample watercourses was highest in the period prior to lining, and had deteriorated steadily since that time (Table 4.1).

Table 4.1. Delivery performance ratios for Khikhi Distributary after each stage of the lining program.

Location	Phase			
	I	II	III	IV
Khikhi Head	0.99	0.98	0.89	0.99
First Quartile	1.04	1.36	1.30	1.34
Second Quartile	0.90	1.07	1.00	1.07
Third Quartile	1.68	1.12	0.75	1.04
Fourth Quartile	1.27	1.16	0.71	0.86
IQR (First/Fourth)	0.82	1.17	1.84	1.55

Note: IQR = Interquartile Ratio.

The magnitude of these changes suggest that there may be other factors involved, such as illegal tampering with outlets during the lining process (such tampering was rampant), that distort the basic changes in hydraulic conditions along the canal. However, if such illegal practices are systematically associated with a lining program, the water savings will not result in improved tail-end water conditions.

Variability of water deliveries to the tail end increased following lining.

The coefficient of variability of daily discharges at the tail has also increased following lining. Following the desilting but before lining commenced, the coefficient of variation of daily discharges during each month were at modest levels (Figure 4.4); following the penultimate stage of lining they are significantly higher at the tail end, and significantly higher when there are substantial discharge fluctuations at Khikhi Head (Figure 4.5).

This may be a reflection of the greater hydraulic efficiency of a lined canal that allows perturbations in discharge at the head to be transmitted more rapidly and effectively along the canal. If total volume increased, then an increase in variability might be of little concern but in a situation where total volume decreases, increased variability is an added constraint to good performance.

The sanctioned cost of this lining activity was approximately Rs 27 million (US\$1.25 million). For a culturable command area (CCA) of 33,500 ha, the capital cost was in the order of Rs 933/ha (US\$37.33/ha).

Figure 4.4. Coefficient of Variation, Khikhi, after desilting, before lining.

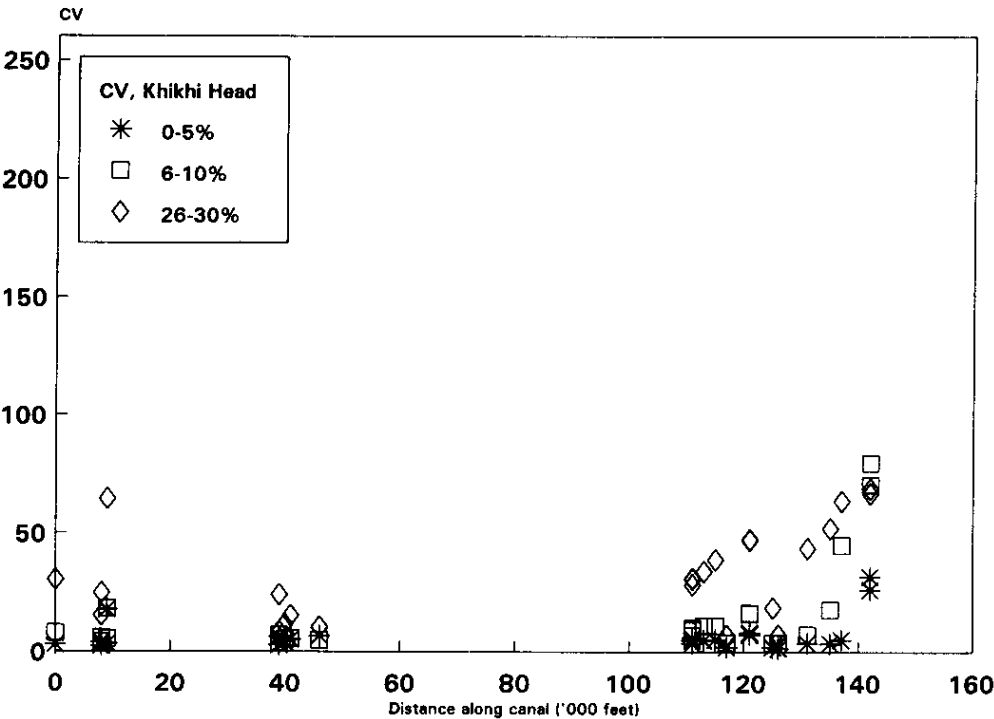
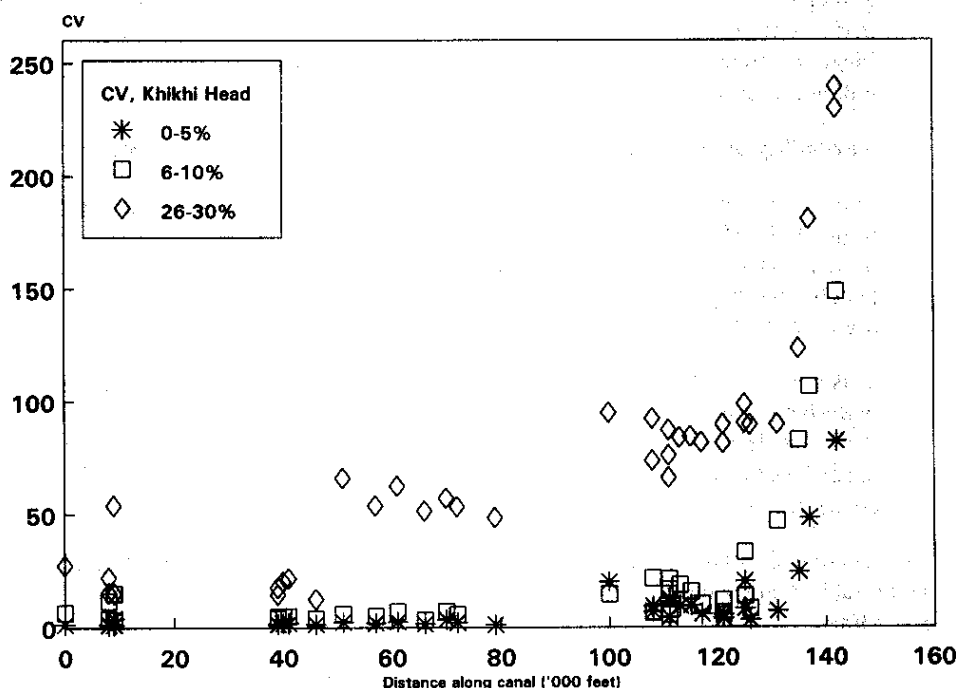


Figure 4.5. Coefficient of Variation, Khikhi, after lining.



One final footnote (which followed the collection of data presented here) to the Khikhi story needs to be reported. By late 1991, following the penultimate lining activity, the portion of Khikhi Distributary that lies on the southern side of the Trimmu-Sidhnai Link Canal and the Haveli Canal were receiving so little water that farmers were successful in getting the Irrigation Department to provide an alternative source of water supply. A special outlet was constructed in the Haveli Canal to deliver water into a specially constructed outlet box which serves the tail bifurcation structure of Khikhi Distributary that lies on the southern side of the link canal. A new tail structure was then constructed at RD 135000, dividing water between watercourses RD 135 and RD 137. This intervention cost about Rs 100,000 (US\$4,000) and utilized funds provided from the discretionary budget of the local Member of the National Assembly, not Irrigation Department funds.

The tail end of Bachrianwala Minor, which is a minor off Khikhi and crosses both Haveli and Trimmu-Sidhnai link canals, was also abandoned, and a new outlet constructed in Haveli Canal. The total cost of these additional changes was Rs 1.2 million (US\$ 45,000).

To put it bluntly, the net result of the activity was the loss of the tails of both Khikhi and Bachrianwala when the very purpose of the lining was to eliminate tail-end water problems.

The primary conclusions of this research are:

- **Lining the tail end of a canal does not seem to solve the problem of water deliveries at the tail.**

If the conclusion that the desilting of the upper half of the canal resulted in favorable tail-end water conditions is correct, then it seems equally logical to focus lining on the

upper portion and try to establish highly reliable and dependable water conditions at the end of the lined section.

- **There is no evidence of water saving as a result of lining.**

Investments in lining are frequently justified because of water savings. The data do not indicate any such savings, but it is possible that benefits from savings, if they exist, have been overshadowed by additional water extraction by head and middle outlets.

- **Implementation of the lining program was disruptive.**

Because it was decided to maintain water deliveries along the entire length of the canal during the lining program, except during the period of annual closure of the entire Gugera Canal System, temporary parallel canals had to be constructed. These temporary sections were highly unstable: innumerable breaches were reported. In addition, it was clear that quality of construction was not up to design standards and this was obvious to farmers. They became increasingly dissatisfied with the work in progress and felt more than justified in making their own illegal interventions.

Further, temporary outlets had to be constructed to serve watercourses while the main canal was closed. There is substantial evidence to show that many farmers took advantage of the disruption to install larger outlets, and even to add additional ones. The effect of these changes, some of which were encouraged by local staff of the Irrigation Department in return for financial considerations, is to further threaten the tail-end supply of water.

- **The desilting program appears to have more impact than the lining.**

The pattern of water deliveries along the Khikhi Distributary measured in the first set of readings is similar to that of both Lagar Distributary and Pir Mahal following desilting (see section on "Maintenance and Desilting" below). It therefore appears that most of the improvements in performance at Khikhi resulted from the desilting program undertaken before lining commenced, and that subsequent lining had no subsequent impact on performance.

- **The total cost is significant in comparison to the apparent benefits.**

The virtual lack of any improvement in performance between desilting and the end of the lining program cannot justify the money expended. In addition, it should be noted that the design adopted for Khikhi was comparatively low-cost. The lining consists of a single layer of bricks placed on a hand-compacted earth foundation with a mortar finish on both side walls and bed. More solid lining would undoubtedly be significantly more expensive and would have to result in improved performance for long periods of time to be cost-effective.

Despite these negative results, it is not possible to merely dismiss lining as a potential solution to the water delivery problems currently encountered in Pakistan. Experiences from many countries suggest that lining, while not resulting in significant savings of water for extended periods of time, does provide an effective datum for maintenance activities. Reestablishing the correct cross section is frequently a hit-or-miss-activity in an unlined canal: it is difficult, if not impossible, to dig out just the right amount of material, not too much so as to maintain effective water depths in the canal, not too little so as to be of marginal benefit.

The lining at Lagar and Ghordaur, although broken in many places after only a few seasons due to back pressure, poor construction, and damage by tractors and buffaloes, nevertheless provides a better overall canal cross-section than in comparable canals that have not been lined.

What is required at Khikhi is a continued set of surveys over the next few years to see whether these potential benefits are achieved. If the canal silts up as rapidly in lined as in unlined sections, and if the lining rapidly deteriorates, then the argument for lining canals in the manner and to the design used at Khikhi is unlikely to provide any economically justified performance improvement.

Further, there has not yet been an opportunity to evaluate the impact of lining of the upper half of a secondary canal. It is highly probable that the results would be better than those reported here, but how much better remains a matter for speculation until a proper evaluation can be conducted.

MAINTENANCE AND DESILTING: LAGAR AND PIR MAHAL DISTRIBUTARIES

One observation made during the initial studies in Lagar Distributary was that water conditions at the head of the lined section were inadequate even though the water conditions at the distributary head were adequate. This observation led to two conclusions:

- However effective lining is, it cannot compensate for poor water conditions upstream of the lined section.
- Further studies are required to understand the hydraulic changes that occurred in the upper two thirds of the canal.

The first set of readings of discharges at every watercourse along Lagar, taken as part of the first phase of intensive field activities, revealed that there was a serious problem of water distribution equity: the tail was almost dry while head-end outlets received in excess of 150 percent of their allocation.

Analyses of these data and surveys of outlet dimensions confirmed that the excess head-end deliveries resulted from higher than designed bed levels in the upper half of the canal, and not from any significant interference by farmers: unless the outlet dimensions are illegally altered, the only way to increase discharge through an ungated structure is to raise the water surface elevation on the upstream side of the orifice. There was little sign at that time that farmers were interfering to any significant extent in terms of building temporary checks.

It was clear that the sediment problem was intense but there was no definitive evidence to indicate what the results of an effective desilting program would be on canal performance. The initial observations in Lagar and the first comparative data sets from Khikhi and Pir Mahal were considered insufficient to come to definitive conclusions concerning the actual benefits of maintenance: comparing poor water distribution in a badly maintained canal with good water distribution performance in a desilted canal 300 km away is hardly good research methodology.

As a result, it was decided to approach the maintenance and desilting issue in a careful and controlled manner in two selected locations:

Lagar distributary was selected because there was already a well-established program for collecting water readings at each outlet every day; because it was adjacent to the IIMI

Field Station at Farooqabad, it was possible to envisage close control over interventions in an action-research phase.

Khikhi could not be used because it was already desilted, but the adjacent **Pir Mahal distributary** proved an ideal alternative. The first set of data from Pir Mahal showed severe water distribution problems, and these were reported to be of similar magnitude to those of Khikhi prior to desilting.

The results of both of these studies are discussed below.

Maintenance Studies in Lagar

Using the hydraulic model developed by Dr. M. Nawaz Bhutta when working with IIMI to undertake his fieldwork for his Ph.D., a proposal was developed in collaboration with the Punjab Irrigation Department to undertake a selective program of maintenance in those locations where desilting appeared to have the greatest potential for performance improvement (Bhutta 1990). This activity was carried out during the annual closure of January and February 1988, allowing IIMI to undertake a comprehensive analysis of water delivery performance before and after the intervention. The full story of maintenance impacts in Lagar has been reported elsewhere (Murray-Rust, Vander Velde and Bhutta 1992).

Despite some evidence to suggest that not as much sediment was actually removed as planned, the results were dramatic. In summary, the selective maintenance had the following impacts:

- **The effects of desilting in the upper reaches of a distributary have a dramatic beneficial impact on water distribution equity.**

Following desilting, the conditions at the tail end improved dramatically: the ratio of head-tail inequity dropped from 4.20 to 1.29 (Table 4.2), a condition never previously recorded from IIMI's own research or from the less reliable but longer term Irrigation Department records.

Table 4.2. Delivery performance ratios for Lagar Distributary, before and after desilting.

Location	Before	After
First Quartile	1.32	1.23
Second Quartile	1.32	1.38
Third Quartile	0.86	1.16
Fourth Quartile	0.31	0.95
IQR (First/Fourth)	4.20	1.29

- **Inequity between head and tail of the distributary was less than inequity among watercourses.**

The changed spatial distribution of water deliveries (Figure 4.6) indicates that following desilting there was greater variability among adjacent watercourses than between head

and tail of the distributary. These localized deviations from design conditions result from deviations from designed elevation or dimension of individual outlet structures. This finding means that the maintenance inputs were more than sufficient to overcome the problems caused by excess sedimentation.

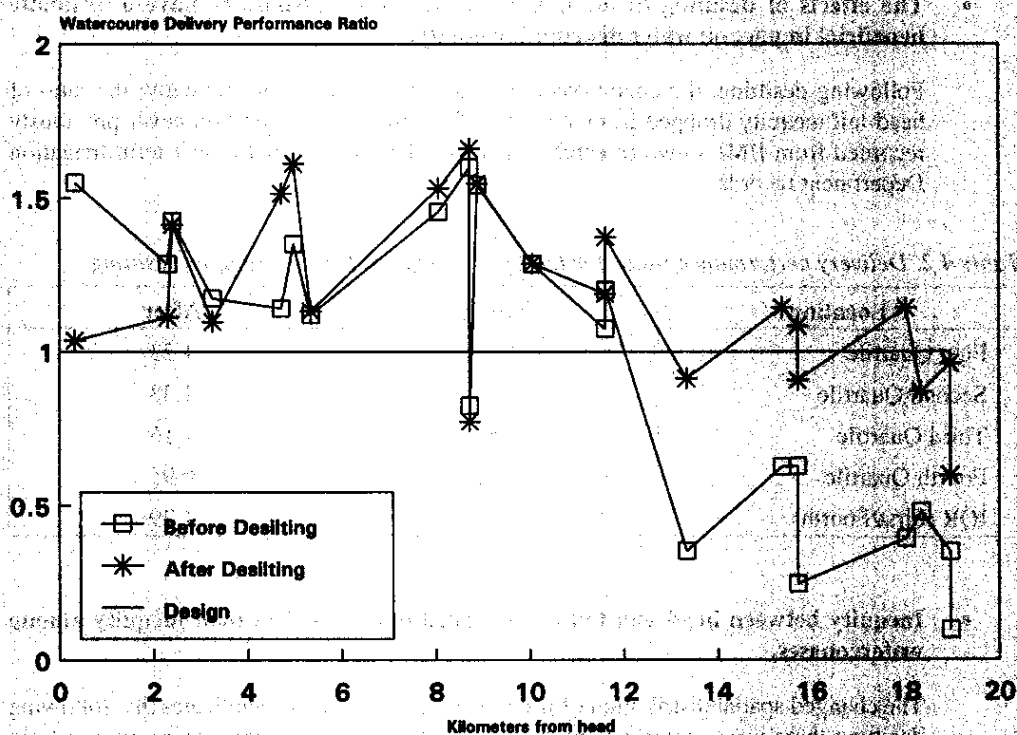
- **The economic benefits of desilting are significant.**

Although the desilting intervention was treated as a special case, the actual cost per hectare of command area was so small that under the most conservative scenario it would likely pay for itself within three years on irrigation charges (*"abiana"*) alone. The estimated cost of intervention was US\$3,600, or US\$0.52 per hectare of CCA, a cost that could probably be recouped within a single year through increased cropping intensity in tail-end areas.

- **Computer-based simulation models are effective as a management tool.**

The hydraulic conditions following changes to canal cross sections and long profile were predicted with a high degree of accuracy by computer simulation. Such predictions enable managers to assess, with considerable confidence, the impact of desilting different portions of a canal and find the most cost-effective way to improve canal performance, if they wish to do so.

Figure 4.6: Lagar Distributary, water distribution equity.



- **Performance improvements following maintenance require parallel operational management.**

The improvements in performance following the maintenance activity only lasted for a few months. The cause for subsequent decline was not physical change but operational reasons. Tail-end farmers who had experienced the best water conditions for as long as anyone could recall found that when the subsequent rice season commenced, upper and middle farmers stole so much water that the tail again started to experience severe water deficits. As a protest, the last quarter of the canal was blocked by farmers in an effort to demonstrate the ineffectiveness of the Irrigation Department in managing water equitably. The problems of water theft are discussed in more detail later (see page 103, "Operations Along Secondary Canals").

Desilting in Pir Mahal

Pir Mahal Distributary and its associated set of minors were in a sorry state of affairs prior to desilting: the ratio between head-end and tail-end DPRs was over 6.0, much higher than those of Lagar. Although it had been targeted for desilting for several years, resources for this purpose could not be mobilized by the Irrigation Department. However, a program for a thorough desilting was eventually implemented in early 1992. In preparation for the evaluation, IIMI undertook a set of measurements during June-August 1991 to determine actual conditions prior to desilting, and a second set of readings for June-August 1992 following desilting. A total of 20 watercourses along the full length of Pir Mahal Distributary were included in the measurement program, with daily readings of discharge taken at each location. In addition, automatic water level recorders were installed at the canal head and at the bifurcation at Junejwala Minor.

A comparison of canal performance before and after desilting shows that there were indeed significant improvements in performance as a result of the intervention. The primary benefits can be summarized as follows:

Canal Capacity

Before desilting, it was only possible only to deliver design discharge into the canal by using the full freeboard: under these conditions the canal is liable to breaching and it greatly favors the upper-end outlets because the operating water surface elevation is higher than designed. Following desilting, it is possible to deliver the design discharge more or less at designed water surface elevations, and to deliver 30 percent more than design discharge by using the full freeboard. The differences in actual discharge delivered into Pir Mahal is shown in Figure 4.7, while the frequency distribution is shown in Figure 4.8.

Measurement Capacity

Before desilting, it was not possible to use the official discharge rating curve for the drop structure immediately downstream of Bhagat Head. This drop structure was drowned out because of backwater effects created by higher than designed bed levels. Following desilting, this drop structure now functions normally, with an effective hydraulic jump downstream making it relatively easy to determine actual discharges into the canal.

Figure 4.7. Discharge into Pir Mahal at Bhagat Head.

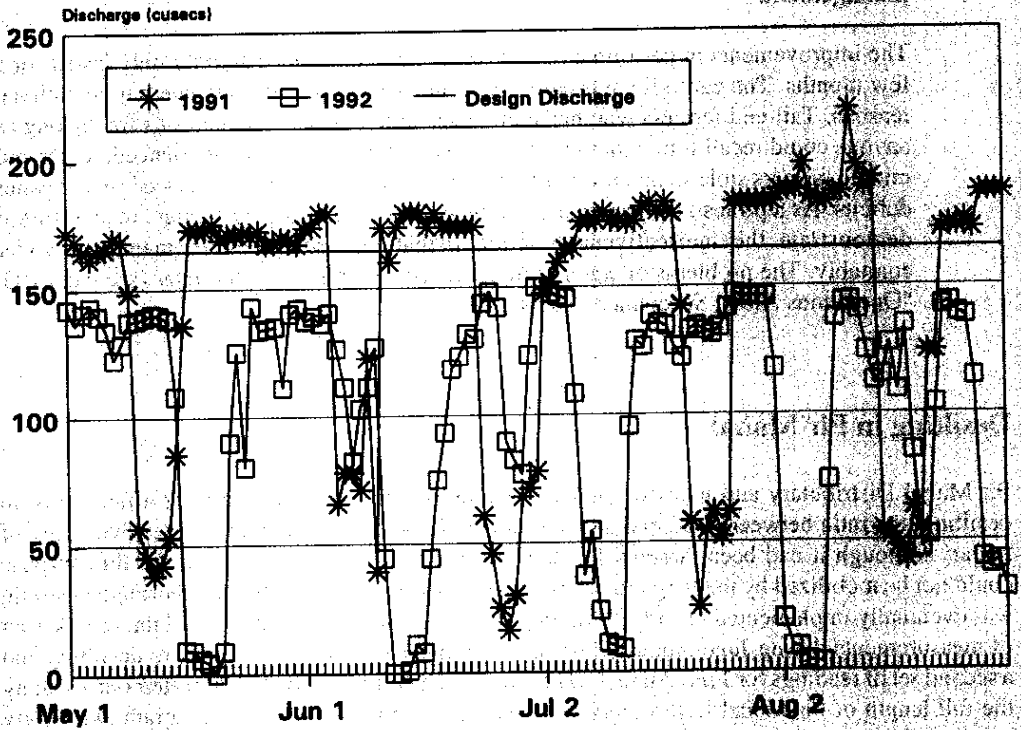
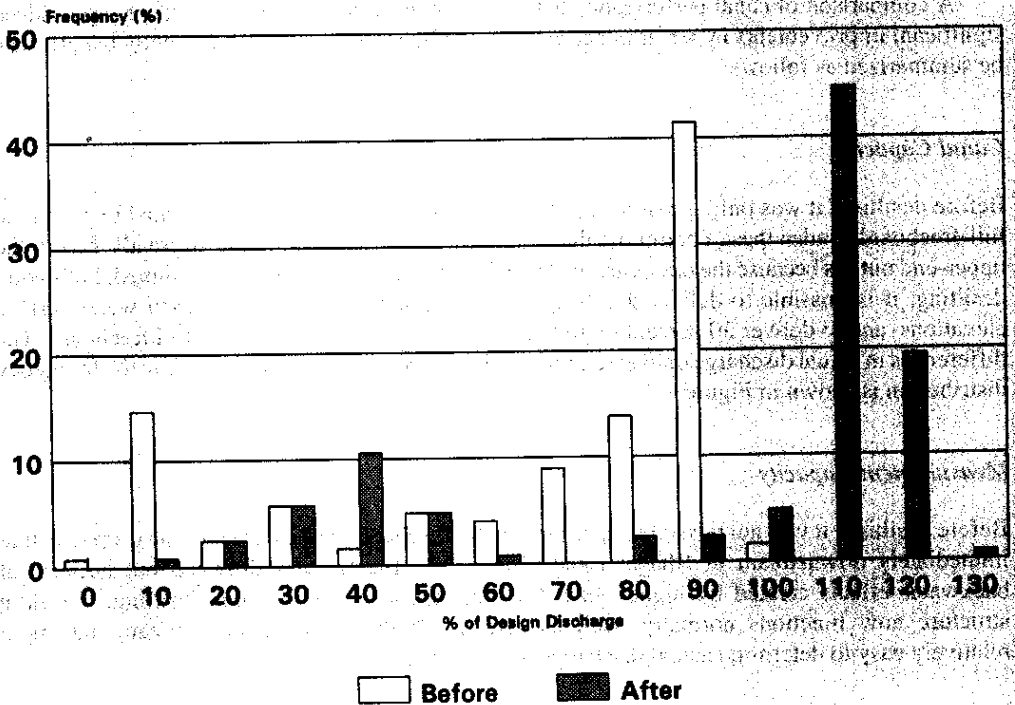


Figure 4.8. Distribution of inflow into Pir Mahal before and after desilting.



Equity of Water Deliveries

Before desilting, the average discharge into the canal was two thirds that of design, with a DPR of 0.67 (Table 4.3). The upper-end watercourses, however, received more than design with a DPR of 1.16, while water deliveries to tail-end watercourses had a DPR of 0.19. This gives an interquartile ratio (IQR) of 6.11. After desilting, the interquartile ratio declined dramatically. With an average DPR of 0.99 in the canal, head-end outlets had a DPR of 1.19 while tail-end areas had a DPR of 0.46.

Table 4.3. Delivery performance ratios in Pir Mahal Distributary before and after desilting.

Location	Before	After
Pir Mahal Head	0.67	0.99
First Quartile	1.16	1.19
Second Quartile	0.94	1.28
Third Quartile	0.49	0.84
Fourth Quartile	0.19	0.46
IQR (First/Fourth)	6.11	2.59

A fairer evaluation of performance can be obtained by comparing the DPRs when the head DPR was more or less the same. For periods when the inflow into the canal was at or close to design discharge, the interquartile ratio improved from 4.42 to 2.03.

However, when discharges were significantly below design, desilting did not result in such high levels of improvement. When the DPR is between 0.3 and 0.5 at the head, water did not reach the tail either before or after desilting. However, it was able to reach well into the third quarter of the canal following desilting, whereas it only reached half way down the canal before desilting.

Internal Rotations

For several years, it has been necessary to implement rotations at Bhagat Head due to lack of water in Lower Gugera Branch. However, due to sedimentation problems along Pir Mahal a secondary rotation had to be implemented at the bifurcation between Junejwala Minor and the tail-end section of Pir Mahal. In the worst conditions, when Pir Mahal was in third or fourth priority, no water would reach the bifurcation, with areas below the bifurcation only guaranteed to receive water during one week in four. Following desilting, the rotations at Bhagat Head still have to be implemented, but rotations are no longer required at Junejwala bifurcation (Figure 4.9). The change in flow distribution at Junejwala Minor before and after desilting show similar improvements (Figure 4.10).

Figure 4.9. Rotations between Junejwala Minor and tail half of Pir Mahal.

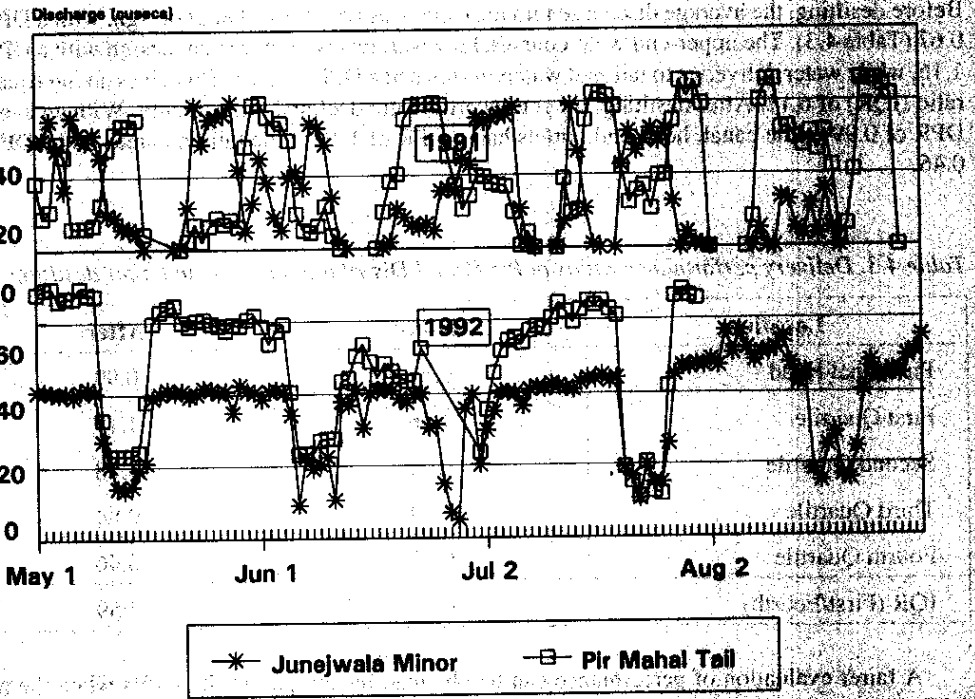
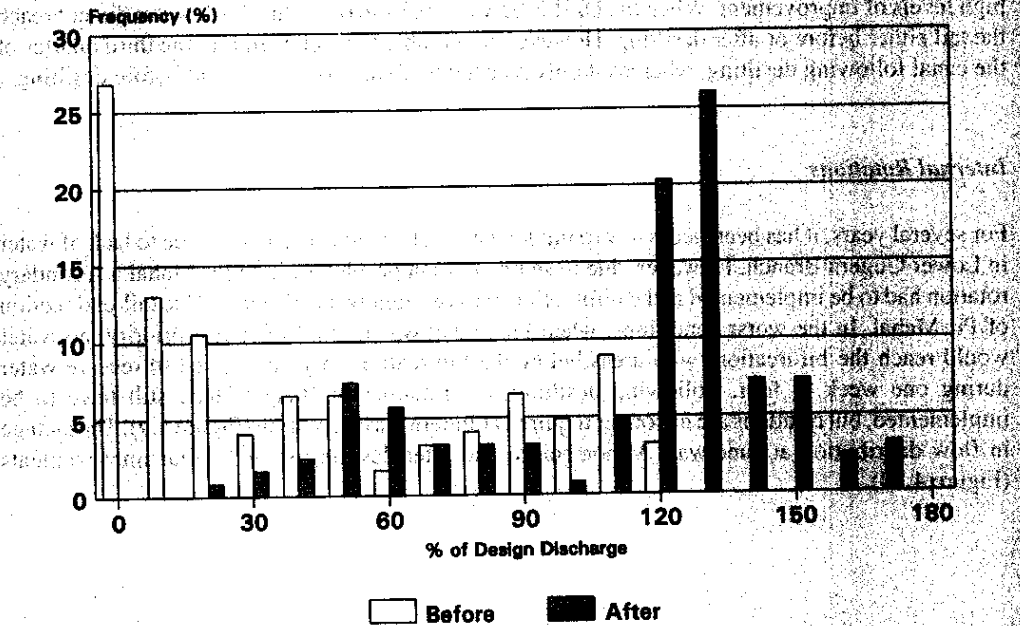


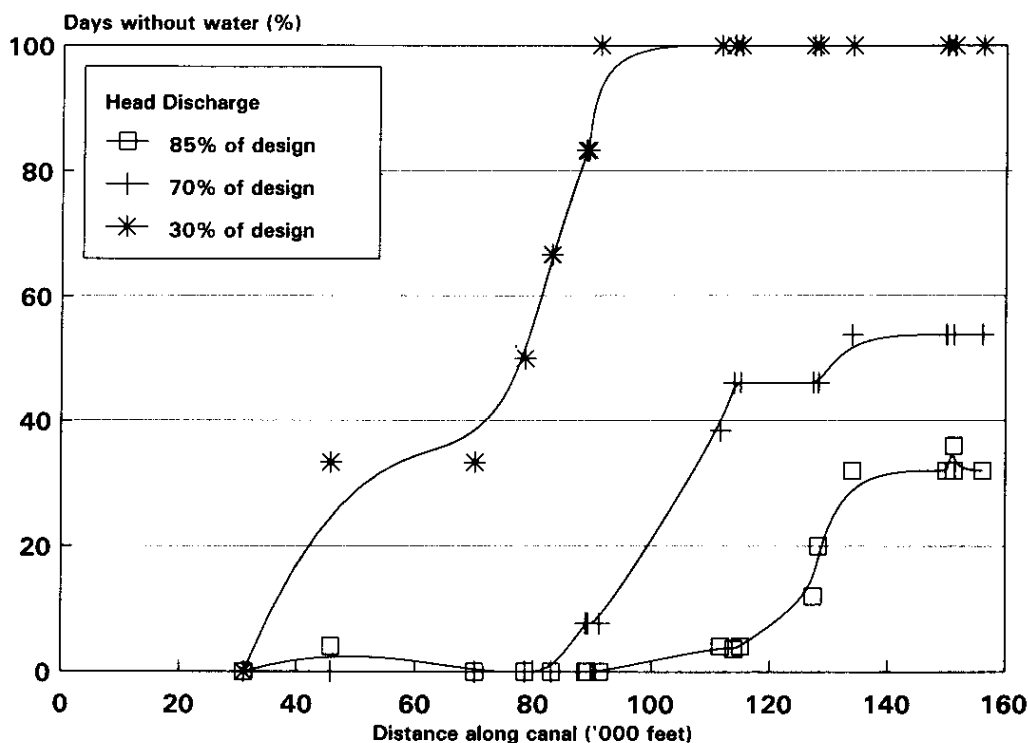
Figure 4.10. Distribution of inflow, Junejwala Minor, before and after desilting in Pir Mahal.



Number of Days without Water

Before desilting, the number of days without water was a major concern. Because of the rotation implemented at Bhagat Head between the different distributaries due to lack of water in Lower Gugera Branch, Pir Mahal did not receive water for about 15 percent of the time. However, due to excess withdrawals at the head, the lower portions of the canal received progressively less water, reaching 45 percent at the bifurcation of Junejwala and the tail of Pir Mahal. Because of the second rotation imposed at this location due to lack of adequate discharge, tail-end areas suffered even more, with watercourses dry 67 percent of the time (Figure 4.11).

Figure 4.11. Number of days without water at different discharges, Pir Mahal, 1991.



Following desilting, this picture changed dramatically. The number of days when water was not delivered to Pir Mahal dropped to 2 percent, rising to 13 percent at the Junejwala bifurcation (Figure 4.12). The improved discharges at the bifurcation meant that the rotation at that bifurcation was no longer required, and tail-end areas were deprived of water only for 33 percent of the time. In other words, following desilting, the tail-end watercourses received water on twice as many days as that before desilting.

Variability of Water Deliveries

Before desilting, the coefficient of variation (CV) of daily discharges over the three-month observation period was 50 percent at the head of Pir Mahal. Upper-end outlets had a CV averaging

Figure 4.12. Number of days without water at discharges, Pir Mahal, 1992.

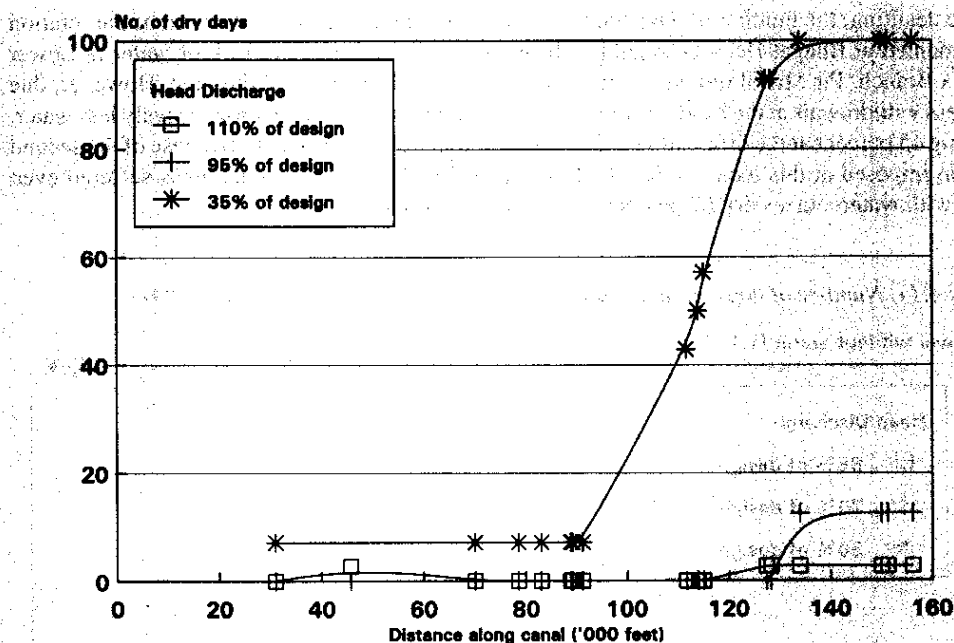
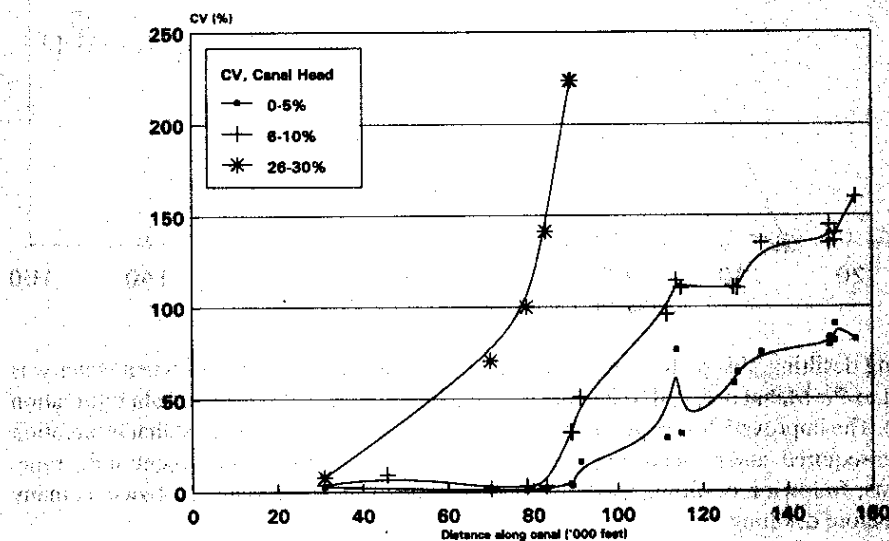


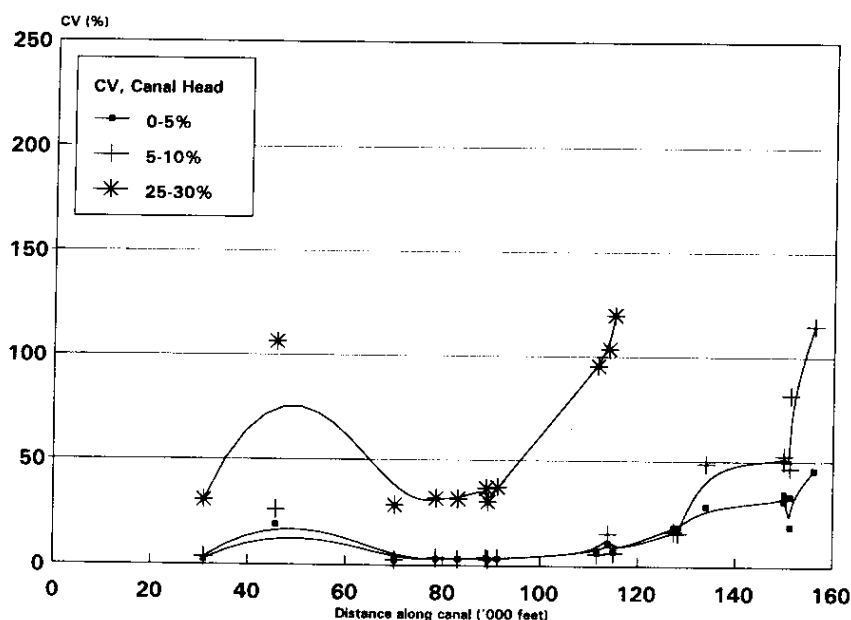
Figure 4.13. Coefficient of Variation of Discharge, Pir Mahal watercourses, before desilting.



60 percent, and increasing to 75 percent by the Junejwala bifurcation. Below the bifurcation, the CV increased rapidly to over 150 percent (Figure 4.13).

Following desilting, the coefficient of variation at the head dropped to 85 percent, and this level of variability remained unchanged down to the Junejwala bifurcation (Figure 4.14). Below

Figure 4.14. Coefficient of Variation of Discharge, Pir Mahal watercourses, after desilting.



the bifurcation, the CV increased but only reached 80 percent by the tail, thus halving the uncertainty in daily water deliveries.

Costs

The total cost was Rs 1.1 million for 18,300 ha, a capital investment rate of Rs 60 (US\$ 2.40) per hectare of CCA. This level of expenditure is approximately 12 times less than that for lining, and yet the benefits are far superior.

These results dramatically justify the massive campaign for desilting that occurred throughout much of Punjab during the closure period of 1992. Tens of thousands of people, including government servants, farmers and, particularly, school children, were mobilized for desilting; massive publicity was given to these actions with political support from the highest levels. Although the reality is that less silt was removed than advertised, there can be no doubt that based on the Lagar and Pir Mahal experiences, water conditions must have improved dramatically.

OPERATIONAL MANAGEMENT AND THE EFFECT ON CANAL PERFORMANCE

The performance of canals, particular those where most water control is achieved by passive water division structures, depend heavily on the proper operation of the few control structures that exist. It is clear that the benefits of either canal lining or desilting will occur only if there is effective operational management.

In this section, two particular aspects of operational management are addressed: those undertaken by the Irrigation Department, and those undertaken by farmers along distributary canals. The combined action of both groups results in sub-optimal canal performance even when the physical condition of canals is satisfactory.

Operations by the Irrigation Department

The operation of long canals with few gated structures should, in many respects, be a relative straightforward matter: canals were designed to run more or less at full design discharge for months at a time. This means that, in comparison to systems in the humid tropics with much denser control infrastructure, the management opportunities in Pakistan are limited in both space and time.

Over the years since the initial phase of construction of canals of this type of design, a set of operating rules and regulations have been developed by the Punjab Irrigation Department for application in the main and secondary portions of the canal system. Among the more important facets of these operating regulations are those dealing with collection of field data to monitor canal performance:

- ***Daily water levels at the head end of every canal***

Most secondary and some minor canals have some facility for measurement of water levels, either a stilling well constructed just downstream of the head regulator, or staff gauges. In a limited number of locations, there are control sections (normally drop structures) that have been installed to permit direct discharge readings to be made, but the topography in most locations does not provide sufficient elevation. These data are entered daily into the records at the Subdivision office and, later, sent on to the Executive Engineer.

- ***Daily readings of water levels at the tail of every secondary and minor***

The tail-end structure of virtually every secondary and minor is a bifurcation or trifurcation consisting of open flumes. Design rules call for a set water surface elevation to be maintained at the tail, frequently 0.7 feet (21.5 cm), sometimes 1.0 foot (30.5 cm). A gauge is almost always installed in the structure. These data are also entered in the daily register.

- ***Monthly readings of water surface elevation in the secondary canal at every outlet structure***

Regulations call for the regular checking of water surface elevations at every outlet structure to ensure that the actual water surface elevation is within the tolerance laid down in design guidelines. These data are collected in the "H" Register.

- ***Discharge calibration***

Periodical measurements of canal velocities are required in order to check whether discharge tables for the head of every main and secondary canal, and some minors, are accurate. These velocity readings, which are intended to be done at several different water levels (actually not easy if canals are to be operated close to design discharge), are to be

determined either by current meter or the use of floats, commonly in the form of velocity rods.

These four pieces of information are sufficient to tell the system manager whether things are operating more or less as intended. To oversimplify matters, the manager needs to know, on a daily basis, that the discharge into the canal is within tolerance and that the tail has adequate water: if both conditions are true, then no action need be taken.

The periodic checking of water levels along the canal ensures that water levels are not higher than the designed level either due to sedimentation or blocking of the canal by farmers. The inflow discharge information is required to determine, in the event the tail is short of water, whether the cause is inadequate discharge into the canal or some problem along the canal. It also ensures that the water allocation into each canal is adhered to.

The final operating rule that is of direct relevance is that discharge into canals should never drop below 70 percent of the designed discharge. This rule makes sound engineering sense: if discharges fall below this level, it becomes impossible to maintain acceptable levels of equity between head and tail of a canal that has no intermediate control structures. If discharges in main canals are not sufficient to meet the 70 percent minimum requirement, then rotations have to be implemented between secondary canals.

Observations made during the past six years merely confirm the worst case scenario:

- Water data are no longer collected systematically at the head of every secondary: although records exist for most canals, the data are not reliable and show increasing deviations from reality. Further, even where data are collected, the canal telegraph system has more or less collapsed and time lags in obtaining data at the managers office are increasing.
- There are hardly any locations where tail-gauge readings are now collected: the data that do exist can be considered completely unreliable.
- No "H" Registers have been filled in since the 1960s: data are not collected.
- There is no evidence that any velocity readings have been taken by the Department (except in connection with research components of special projects such as Command Water Management, Irrigation System Rehabilitation Project, etc.).
- No set of velocity rods has ever been seen by any IIMI staff in any office, although requests to see them are made as a matter of principle.
- Discharge rating curves are decades out-of-date, most are inaccurate at best, wrong at worst.

The result of these conditions is obvious: system managers do not know what is going on in their areas of responsibility. They clearly do not care about canal performance. The consequences are, however, very serious. A single example will demonstrate this.

From the very outset of IIMI's work, analyses using the daily observations from Lagar Distributary showed that the canal was being operated for substantial periods well below the 70 percent limit. There is a clear relationship between the actual discharge into Pir Mahal (as a percent of design discharge) and the inequity along the canal (Figures 4.15 and 4.16). Identical trends are found in Khikhi and Lagar despite the very great difference in their design discharges.

Figure 4.15. Delivery performance ratios, Pir Mahal sample watercourses, before desilting.

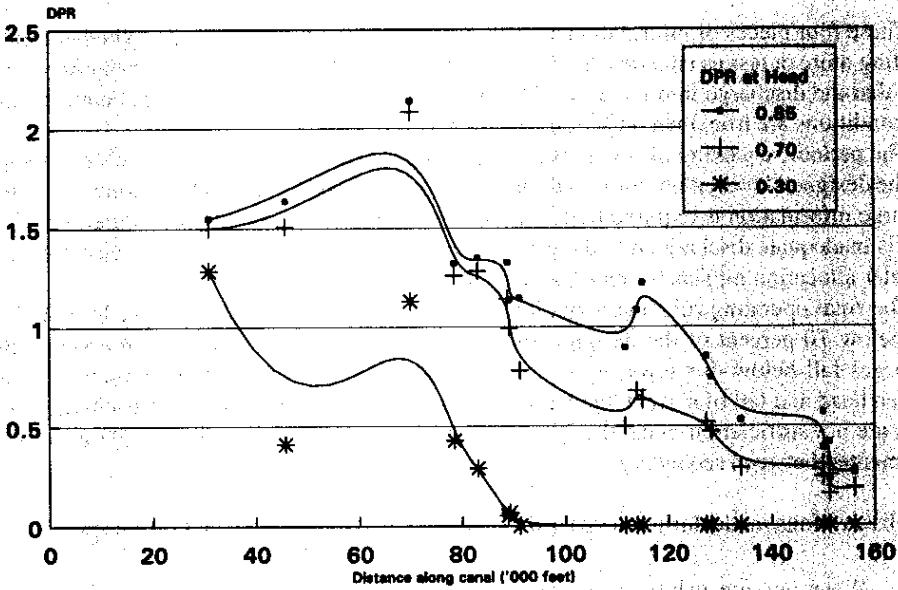
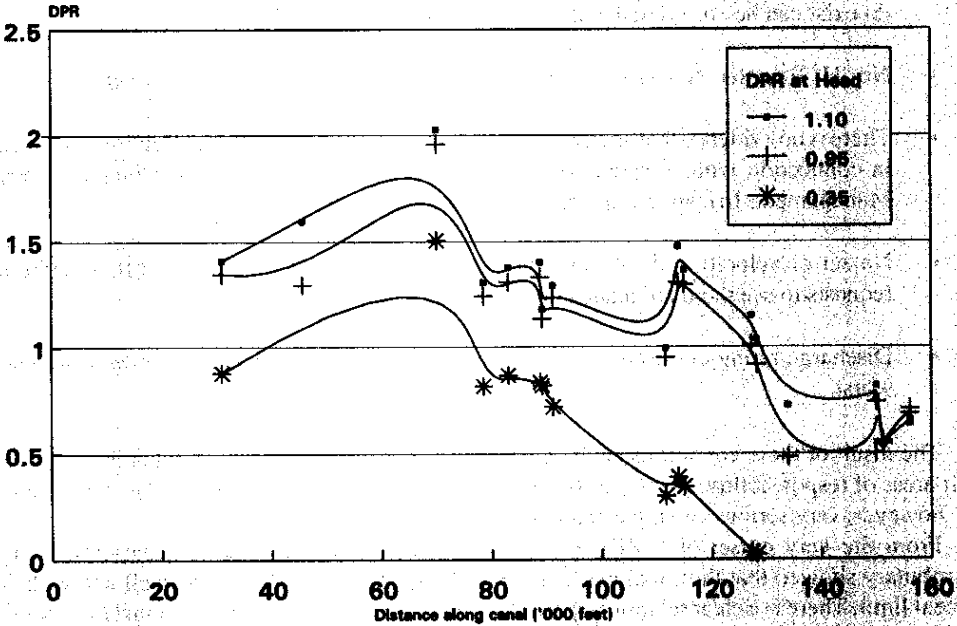


Figure 4.16. Delivery performance ratios, Pir Mahal sample watercourses, after desilting.



Whenever canals are operated below the design limit, water conditions at tail-end outlets deteriorate rapidly to the point where tail outlets dry up while upper-end outlets still receive supplies close to the design discharges. These empirical observations were subsequently confirmed through simulation analysis.

The data presented here appear to be representative: almost identical results have been obtained from all canals studied under the IIMI program. This is hardly surprising because the inequity measured can be calculated using hydraulic principles, which, after all, are the basis of the design of the entire Indus Basin canal network. What was known 100 years ago has been forgotten or just ignored.

It would be possible to describe at length the deficiencies in the actual operation of canals observed over the past six years. It is perhaps easier merely to express it all along the following lines:

The capacity to measure water in a canal system, particularly where water is the scarce resource, is fundamental to irrigation. It is inconceivable that major corporations would operate without knowledge about sales, markets, profits and losses, but this is precisely what most irrigation agencies, including those in Pakistan, are doing at the moment (Murray-Rust and Merrey 1992). They do not know how much water they put into the system, they do not know where it goes within the system, and they are care-less. To even imagine that irrigation departments respond to agricultural performance when they cannot measure water is unrealistic.

Until this attitude changes, there is really little reason to believe that performance will improve. It matters little whether canals are lined or unlined, maintained or allowed to deteriorate, if there is no capacity to operate the system and measure water. All evidence, albeit unscientific, suggests that the rate of deterioration of repaired, rehabilitated, or even new canals is so rapid that any performance improvements are bound to be short-lived.

In short, the issue is primarily an institutional one rather than a technical one. Although technical competence may not be as high as might be desired now, any change there without an improvement in the current institutional setting and attitudes is unlikely to result in any significant benefits. At the same time, it is fair to say that irrigation agency staff are only half of the problem. Farmers too contribute their fair share to undermining canal management.

Operations Along Secondary Canals

It remains conventional wisdom that once water has entered into a canal, distribution is controlled by passive structures. Farmers have long been assumed to have only a capacity to manage water within the watercourse although reports of illegal tampering of outlets have occurred for decades. It is apparent that at more or less the same time the Irrigation Department began to lose control over the secondary canal system, farmers started to have a more direct impact upon distributary-level water distribution. Which came first is hard to tell, since there are records available of water thefts and outlet tampering from the earliest days of canal operations.

What is clear is that the capacity to prosecute farmers who tamper with outlets or are engaged in water theft has been lost now. Such activities can be done with little risk of prosecution because agency staff will sell immunity and sanction illegal activities for various considerations, or politicians and other influentials will provide protection. In these matters, of course, farmers themselves are not necessarily any more altruistic than government officials. What is of research

interest to IIMI is to try to determine the relative magnitude of farmer interference in comparison to the operational failings of the irrigation agency.

Field observations along many distributaries over several years have confirmed that from late February through April there is relatively little stress on the canal system in Punjab. Evapotranspiration rates are fairly low, though slowly rising, and rainfall prospects are reasonable. Wheat, the dominant winter crop, is approaching maturity and ripening for harvest or else is sufficiently mature not to require significant irrigation. The other important crop at this time, various fodders, occupies a comparatively small percentage of the total command area. Thus, farmers in head-end watercourses do not need excessive amounts of water and there are frequent instances when one or more outlets are fully or partially closed for two or three days, often in response to rainfall.

Following this period of relative peace and harmony, from late May onwards, observations along selected canals show a marked upsurge in interventions undertaken by farmers to appropriate additional water in the upper two thirds of the channel, peaking in number from late July to early September. These events include direct cuts, breaches, the installation of both illegal and sanctioned pipes, blocks in the distributary, siphons, and so forth. Parallel field observations in the bottom one third of these canals reveal a simultaneous "collapse of the tail," whereby water no longer reaches the end of the distributary.⁷ Once the rice crop has become established and water requirements begin declining with reduced evapotranspiration demand toward late September, the frequency of such interventions also decreases. IIMI's initial analyses of these conditions were mainly subjective, providing further anecdotal evidence of distributary head-tail differences.

What was required was a more careful and incontrovertible analysis of the location, magnitude and timing of the effects of such interventions. A promising methodology has been developed that permits expected discharges to be calculated for all measurement points along a secondary canal based on the discharge at the distributary head and other key upstream locations as may be required. This methodology relies on the use of running averages, required to smooth the variability introduced by discharge fluctuations in main canals and to eliminate the effects of hydraulic travel time along canals, and regression techniques. The resulting analysis follows a somewhat different approach to those previously undertaken in the IIMI-Pakistan program because it is possible to relate measured performance at selected locations with predicted values.

During the quiescent March-April period, when canal hydraulic conditions are as free of external interventions as they ever are, running averages of discharges into canals and into selected watercourse outlets along the canal are calculated.⁸ The resulting values are converted to delivery performance ratios (DPRs) to permit locational comparisons. The entire set of daily DPR values for a watercourse for this period are then regressed against the corresponding set of independent distributary-head values. The correlation coefficients of these comparisons, even between head-end and tail-end discharges along longer canals, are remarkable high, rarely falling below the r-squared value of 0.8, and almost inevitably significant at the 1 percent level.

Assuming the relationship as hydraulically valid, it is then possible to use the regression results to calculate the DPR for each watercourse for the rest of the year if external interventions to appropriate water from the canal remain at the March-April minimum. These predicted values then can be compared directly with actual DPRs calculated from daily field measurements. The results of these analyses are briefly summarized below for one year, 1990, for one canal, Mananwala distributary, in Farooqabad Subdivision, Upper Gugera Division, of the LCC system. Similar

7 It has been officially acknowledged during the past year that 40 percent of all secondary canals in Punjab have, like the "three blind mice," "lost their tails."

8 A fifteen-day running average (seven days before and seven days after the date of observation) was found to give the most satisfactory results.

results have been obtained for other years and for other distributaries, strongly implying that the findings describe here are not merely an example of a special case.

The results obtained by this approach demonstrate the near catastrophic impact of upstream water theft, whether or not "sanctioned," on tail-end water conditions in Mananwala distributary.

MANANWALA DISTRIBUTARY: INTERVENTIONS AND PERFORMANCE

- The head-end watercourses do not reflect the just inflow pattern at the distributary head; their DPR values clearly show a substantial and systematic increase in water deliveries into head-end outlets. Such changes in DPR cannot be explained solely by hydraulics; it also involves deliberate enlargement of offtakes through several means and/or the partial blocking of the distributary. The variety of head-end interventions in Mananwala command have now been well documented over a several-year period (Figure 4.17).
- Middle-reach watercourses, as well as those at the upper end of the canal tail reach, appear to pretty much hold their own with interventions here largely compensating for the impacts of those upstream. Field data indicate that various interventions *between* watercourse outlets here are numerous during the peak water theft period, July–September, but their effects on outlet DPRs are not really experienced here (Figures 4.18 and 4.19).

Figure 4.17. Mananwala Distributary performance, Outlet 23R: Actual and predicted DPRs.

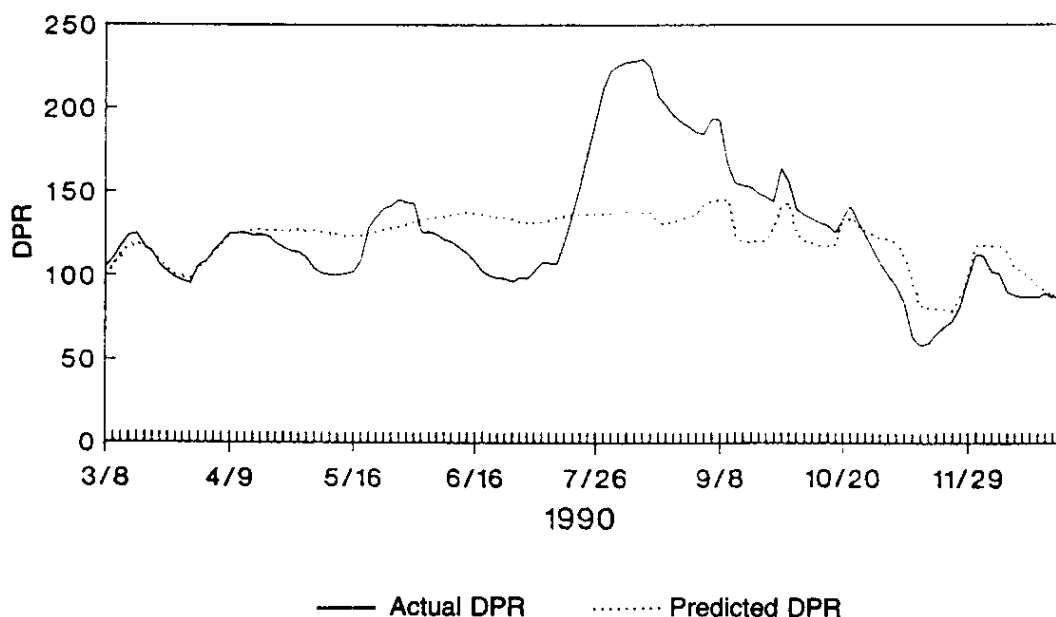


Figure 4.18. Mananwala Distributary performance, Outlet 121R: Actual and predicted DPRs.

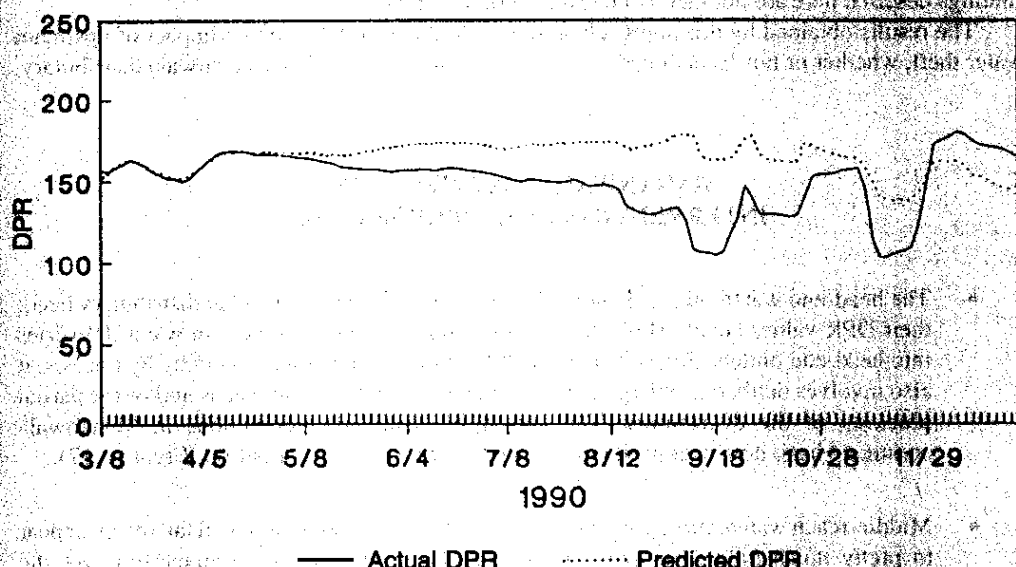
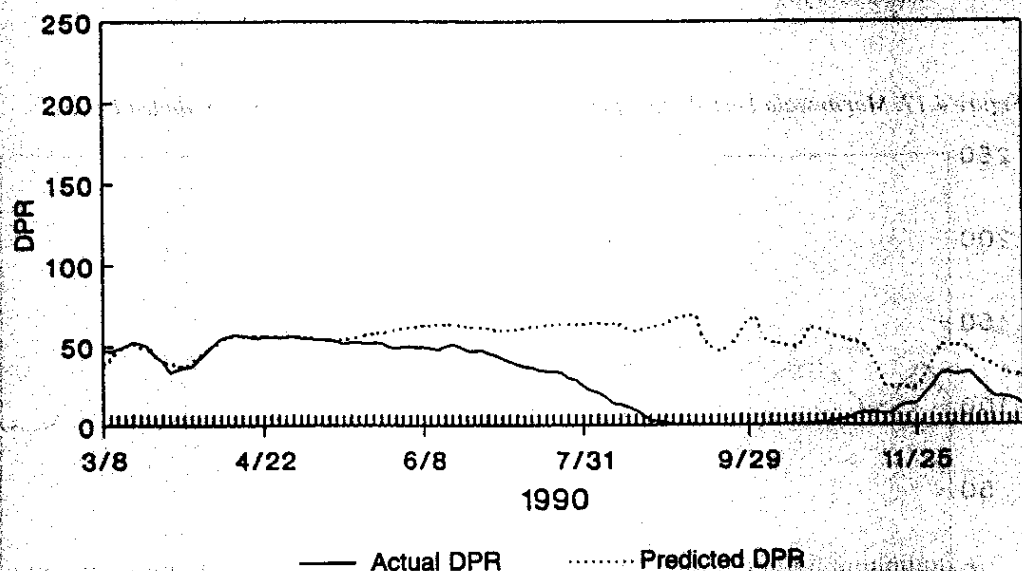
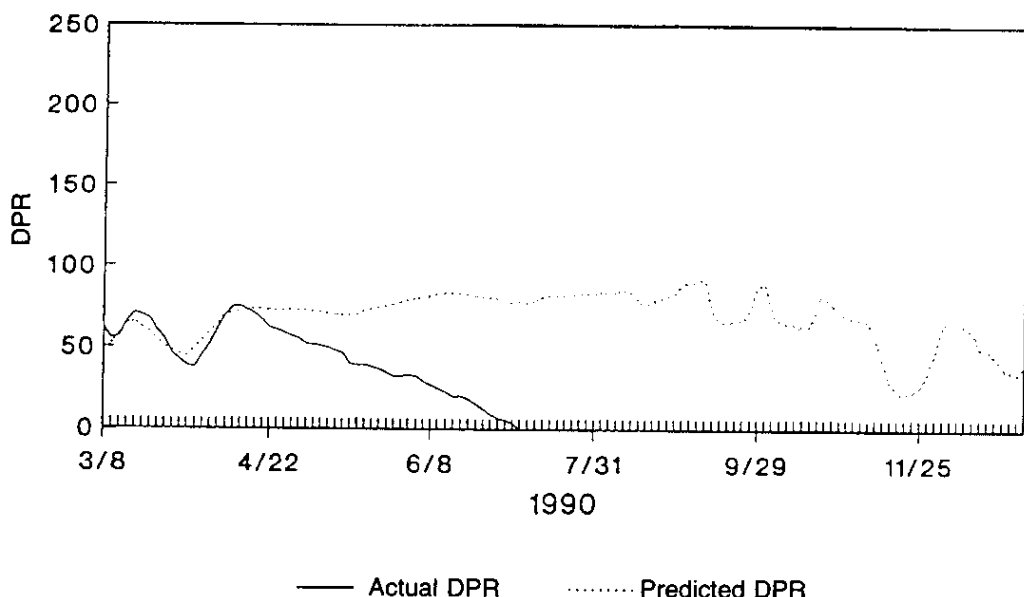


Figure 4.19. Mananwala Distributary performance, Outlet 141R: Actual and predicted DPRs.



- The distributary tail disappears. Watercourses in the last half of the tail reach have virtually no surface water throughout the entire summer season. Whatever the farmers grow must be irrigated with tubewell water only, and this is, as will be clearly demonstrated in Chapter 8, of sufficiently poor quality to induce rapid increases in substantial secondary soil salinity to levels that will inevitably reduce crop yields (Figure 4.20).

Figure 4.20. Mananwala Distributary performance, Outlet 148TR: Actual and predicted DPRs.



In some respects, it is amazing that tail-end farmers do not protest more strongly than they currently do. Everybody knows that water theft goes on, either independently or in connivance with irrigation agency staff. Reclamation and "Grow More Food" shoots, kharif season outlets that can be legally sanctioned *only* when it is certain that their discharges will not reduce water supplies at the tail, are sold to high bidders and other influentials by the Irrigation Department at the explicit expense of tail-end farmers.

ECONOMIC EVALUATION

Perhaps the most dramatic analysis of the results is that relating to the economic benefits of the different approaches. The cost of each intervention is presented in Table 4.4: the benefits have been calculated on the percentage improvement of the Interquartile Ratio following the intervention. The poor performance of lining is obvious, with a negative rate of return. For the two desilting interventions, the results suggest that minor desilting at frequent intervals may be the most efficient solution but this conclusion requires data on the return period of less intense desilting in comparison to more extensive but less frequent desilting.

The choice between different interventions depends on both hydraulic performance improvements and the cost of the intervention. Data exist for each intervention that allow an economic evaluation to be made, using an assumed interest rate of 10 percent.

Table 4.4. Comparative costs of different interventions.

		Interquartile Ratio (IQR)		Cost		Change in IQR	
Canal	Activity	Before	After	US\$ '000	\$/ha	%	\$/ha
Khikhi	Tail-end lining	0.82	1.55	1,250	37.33	- 57	-1.5
Pir Mahal	Major desilting	6.11	2.59	42	2.40	+144	+60
Lagar	Minor desilting	4.20	1.29	3.6	0.52	+225	+433

Focused Desilting in Lagar Distributary cost US\$3,600, an average investment of US\$0.52/ha. Incomplete observations suggest that the silt excavated was equivalent to three-years accumulation (Murray-Rust et al. 1993). The net annual cost is therefore US\$0.21/ha. For Pir Mahal, the total cost of the major desilting was US\$42,000, or US\$2.54/ha. This is equivalent to US\$0.40/ha if the benefit of such an activity is 10 years, or US\$0.33 if the benefits last as long as 15 years.

For the lining at Khikhi, the total cost was US\$1,250,000, or US\$37.73/ha. If, in line with normal project assumptions, the lining were to last 30 years, the net annual cost would be US\$4.00, roughly 20 times more expensive per ha than the focused desilting at Lagar and ten times more expensive than major desilting at Pir Mahal.

There are no accurate data available on either the rate of sedimentation in secondary canals or the relative life length of each type of intervention studied. Annual monitoring of conditions continues in order to quantify more precisely the assumptions made in this paper. If the focused desilting at Lagar were required annually, then it would cost the same to desilt Pir Mahal every 6 years. Lining, as undertaken at Khikhi, would be eight times again as expensive, if it had a life length of 30 years.

Field observations of the lined sections of canal in Lagar and Khikhi suggest that life lengths are far less than 30 years. In both cases, a decision was made to go for a relatively inexpensive lining consisting of a single brick surface on both beds and banks covered by a thin cement plaster coat. This type of construction is susceptible to back pressure, collapse and damage by both animals and agricultural equipment. A more durable lining is inevitably more expensive; however, given the results of this study, it would not appear to be warranted.

It is also relevant to note that the lining process in both Lagar and Khikhi lacked rigorous quality control, resulting in a substandard lining because of substantial wasted expenditures on labor and materials. Furthermore, extensive tampering with outlets in both lined and unlined sections of Khikhi was tolerated so that many watercourses now receive more than their design discharge.

CONCLUSIONS

Several conclusions have been drawn in the main text of this paper and will only be referred to here in summary.

Improving Performance

There are three components of any effort to improve performance in the secondary canal system in Pakistan: physical upgrading, effective maintenance and focused operations. The results of this study strongly suggest the following:

- Lining of the tail ends of canals fails to lead to any noticeable improvement in canal performance, and cannot be seriously considered as a development strategy.
- Lining of upper portions of canals is likely to prove more effective, but only where sedimentation is not going to recur within a time frame dictated by the economics of the lining program. No data exist on rates of sedimentation in lined canals: they need to be collected.
- There is no evidence that brick and mortar lining leads to significant savings in water along canals. Savings are low due to leakage or due to water theft along canals exceeding any potential savings.
- It is possible to calibrate computer models of the hydraulics along secondary canals relatively quickly and easily, and use these models to identify locations which should be given priority in maintenance using the limited resources available.
- The benefits of maintenance and periodic heavy desilting appear to far outweigh lining, both in terms of hydraulic performance and in terms of cost-effectiveness.
- Operational discipline is essential irrespective of canal conditions: failure to observe basic design principles will inevitably lead to reduced canal performance.
- The institutional capacity to operate canals according to design guidelines is inadequate: routine data collection has broken down, and the data collected is virtually useless due to inaccuracies.
- The ideal combination of activities for improving canal performance is likely to be the maintenance of canals coupled with disciplined operations: physical interventions such as lining should only be resorted to when there is clear evidence of specific technical conditions that will be guaranteed to be overcome by physical changes to the canal system.
- Changes in the institutional setting are a precondition for changes in canal performance. It is impossible to imagine that any technical improvements, adoption of new methods such as computer modelling, etc., have any chance of becoming part of regular activities within the settings provided by irrigation agencies in Pakistan.

Research Implications

The results presented in this report, together with other research activities referred to herein, represent the culmination of a long-term program. While it is true that at various times within the life length of these activities there were specific projects that received external support, there has been a consistent and common thread throughout. This contrasts distinctly with the conditions that have occurred in project-dominated activities: sites change sufficiently frequently that no

long-term records are built up, data collection programs in different sites are different and comparisons extremely hard to make.

This common thread enables the following conditions to be met and achievements accomplished:

- The capacity to measure the same parameters in the same location over a sufficiently long time frame to make sure that results are consistent and representative.
- The capacity to measure precisely the same parameters in other locations under the same conditions to facilitate comparison between locations.
- The capacity to be able to return to documented and stable locations to make repeat measurements after extended periods of absence.
- The capacity to review results periodically with the same researchers irrespective of whether they are based in Pakistan or not, and thus design the next stage of the program in a coordinated fashion.
- A coordinated and systematic data retrieval and storage program that enables access to past data sets by researchers other than those who originally designed or collected the data.
- A significant element of this research program is that there is an ever-increasing capacity to accurately predict the consequences of interventions. There is always a place for action-research programs that foster an intervention and then record the results; there is also a place for somewhat more classical scientific research that can effectively predict results.
- Because results are consistent, because the research methodology is consistent, and because the objectives are consistent, it becomes possible to slowly but surely get the message across. It is inconceivable that the recognition of "missing tails" would have occurred as the result of several projects spread over the same time period using the same resources (after all, USAID had spent millions of dollars for research on irrigation, and there had been no change institutionally except an increased desire to get even more resources).

Policy Implications

The policy implications of this study are clear. Lining of canals carried out in the manner observed in Khikhi would be a complete waste of resources. As it is, the Punjab Irrigation Department has proposed borrowing US\$1.0 billion to undertake the lining of canals as part of the Provincial Water Sharing Accord. The Khikhi experience was a failure for three primary reasons: lining was almost certainly carried out in the wrong location, the quality of construction was very poor with large amounts of money disappearing during construction, and there was active and passive connivance in modifying the size of outlets during lining at the expense of tail-end farmers.

If each of these three conditions could be significantly improved (i.e., lining of upper reaches first, good quality construction with minimal financial leakage, and strict prohibition of tampering of outlets by farmers and agency staff alike) then there is probably a good case for lining. Data

from the Indian Punjab (Upton and Chancellor-Weale 1988) suggests that lining does not result in significant improvements unless groundwater is already saline:

"The general conclusion that must be drawn is that further expenditure on canal and watercourse lining in the Indian Punjab would be difficult to justify in economic terms.

Watercourse lining over 75% or more of the length does not appear to yield an economic return No attempt was made to estimate the returns to lining a small proportion of the length, say 30%, but it seems doubtful whether even this level of lining could be justified economically."

The alternative is to reestablish a proper program of desilting with work focused on areas where performance is least satisfactory. This requires two conditions: sufficient data on actual performance to identify locations where conditions are particularly bad, and a capacity to determine the appropriate intensity of desilting to achieve an acceptable level of performance. Both these conditions could be met if the institutional will is rejuvenated. The collection of performance data (tail-gauge readings and "H" Registers) has lapsed; the computer model developed by IIMI allows desilting impacts to be assessed prior to actual intervention. These would form a substantial element of a Decision Support Package for irrigation managers but to date institutional interest is marked more by reluctance or apathy than active interest.

The same is true for operational improvements. Much of the water theft observed is institutionalized by the sanctioning of additional pipes in blatant contravention of the stipulation that such pipes can only be installed if tail-end farmers do not lose access to their water.

One thing is sure, however. The present management of the canal system in Pakistan is leading to rapid decline in irrigation infrastructure and contributing to the rapid increase in secondary salinization in areas where surface water supplies are inadequate (Kijne and Vander Velde 1991; Kijne and Vander Velde 1992; Vander Velde and Johnson 1992; Murray-Rust and Vander Velde 1992). If policymakers at the highest levels of government and the senior members of the provincial irrigation departments do not act to improve matters, then there is a very distinct possibility of a rapid and irreversible collapse of a highly productive irrigated agricultural system.

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CHAPTER 5

Performance Impacts of Management Transfer in the Columbia River Basin Project⁹

Mark Svendsen and Douglas Vermillion¹⁰

INTRODUCTION

CURRENTLY THERE IS keen interest in many developing countries in transferring responsibility for operating large, publicly constructed irrigation systems to the farmer-beneficiaries of the system. The reasons for this interest vary from country to country, but at its root are the high and unrecovered cost of operating and maintaining large, public irrigation systems and the perception that management can be made more efficient, effective, and sustainable by involving farmers directly in the management of the schemes.

While attracted by the promised benefits, policymakers and agency directors formulating irrigation policies are concerned about the outcomes and wider impacts of such transfers, their institutional and financial sustainability, and the actions required of government to facilitate the transfer process and to support and sustain the new managing organizations. Governments are also concerned with the fate of irrigation agency staff whose jobs are eliminated with possible new roles for their irrigation agencies following the change.

In some countries such as the Philippines and Chile (Korten and Siy 1989), the process of devolution of responsibility to farmers has moved forward deliberately and methodically over a period of years with considerable success. Other countries are pushing rapidly ahead with transfer policies and programs, sometimes with little appreciation of the difficulties involved and little awareness of experience which has been gained in other settings. The overall purpose of this paper is to document the largely successful experience of a more developed country with this process and to explore its implications for others following this path.

The United States has had a policy mandating the transfer of managerial responsibility for publicly developed irrigation to users for almost 100 years. As a result, considerable experience with the process is available. This study of irrigation management transfer in the Columbia Basin Project (CBP) in Washington State, USA provides insights into a number of issues of concern to developing-country policymakers and managers and finds greater similarity of issues and responses in the two settings than might be expected. Since management transfer in the CBP occurred in 1969, sufficient time has elapsed for longer-term impacts to become evident, while the transfer process is still recent enough to be examined through interviews with participants. In addition, excellent hydrologic and financial data are available both before and after the transfer, facilitating quantitative analysis of impacts.

⁹ This is a preliminary report on the research study. A comprehensive, revised report is to be published separately.

¹⁰ The authors wish to thank Bernd Maier of Washington State University for his very capable help in assembling secondary data for this study and Martha Sullins of IFPRI for assistance in data analysis.

In discussing the study of this process, Vermillion (1991) poses four broad generic questions regarding management transfer: 1) What are the impacts of transfer on the hydrologic, agricultural and economic performance of irrigation systems? 2) What key legal, policy, infrastructural, or institutional issues must be addressed to support successful management transfer? 3) What kinds of reorientation of agencies and farmers are needed to support turnover? 4) What kinds of turnover processes and self-management models work best in different environments?

The present study approaches the topic with these questions in mind. It is concerned both with the transfer process and with the results of the transfer and addresses the following specific questions: What forces acted on both government and farmers to compel a negotiated transfer of responsibility? What factors seemed most important in the success of negotiation and transfer? What were the impacts of the transfer of management responsibility on system hydrologic performance, hydrologic efficiency, agricultural performance, financial efficiency, and sustainability? And, finally, what lessons can be drawn from this experience to guide and benefit others?

COLUMBIA BASIN IRRIGATION PROJECT

History¹¹

Efforts at developing irrigated agriculture in the Columbia Basin of Washington State go back to the turn of the century, when numerous attempts at irrigation development were made by companies, private individuals, and cooperatives. As experience with these early, largely unsuccessful experiments with private development began to accumulate, the public sector became more directly involved.¹² The project was finally approved by the newly elected President Franklin Roosevelt and was included in the new Public Works Administration program the following year. The first surveying stakes for the axis of the dam were driven on 9 September 1933.

The centerpiece of the CBP is the Grand Coulee Dam which blocks the Columbia, the fourth largest river on the North American continent, forming the Franklin D. Roosevelt (FDR) Lake, a reservoir extending 151 miles (244 kilometers [km]) upstream to the Canadian border. The CBP was designed as a multipurpose project for irrigation, power generation, navigation, flood control, and stream flow regulation (Infanger 1974), with recreation and wildlife conservation becoming increasingly important objectives in later years.

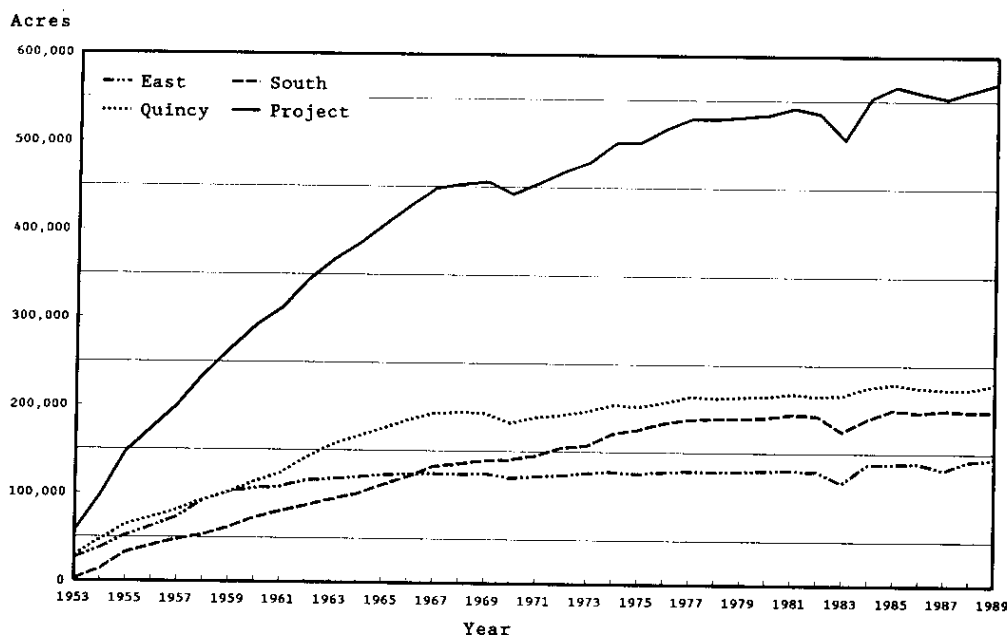
In 1951, the first test water flowed toward Columbia Basin farmland (USDI 1978). Over the next 16 years, the area irrigated by the project increased steadily at a rate of about 25,000 acres (10,000 hectares) per year, reaching a total of 448,000 acres (181,000 hectares) in 1967 (Figure 5.1). Since then growth has continued, but at a much slower pace, and in 1989 the project irrigated approximately 570,000 acres (231,000 ha).

As of 1986, US\$1.687 billion had been spent on construction of the Columbia Basin Project, including the dam, irrigation facilities, and the 6,500 megawatt Grand Coulee hydroelectric power plant complex. Eighty-eight percent of the total construction cost is to be paid for by power revenues, with interest, while 12 percent will be repaid by irrigation fees, without interest.

¹¹ This discussion is based largely on material contained in U. S. Department of the Interior, Bureau of Reclamation (1978).

¹² According to the Pacific Northwest River Basins Commission (1971), 70 percent of the irrigation development in the region was initiated by individuals, cooperatives, and agencies other than the Federal Government, although a major portion of the irrigated area did receive some federal support.

Figure 5.1. Area irrigated (acres), CBP, 1953–89.



Source: Water Distribution Reports for the CBP, U.S. Bureau of Reclamation.

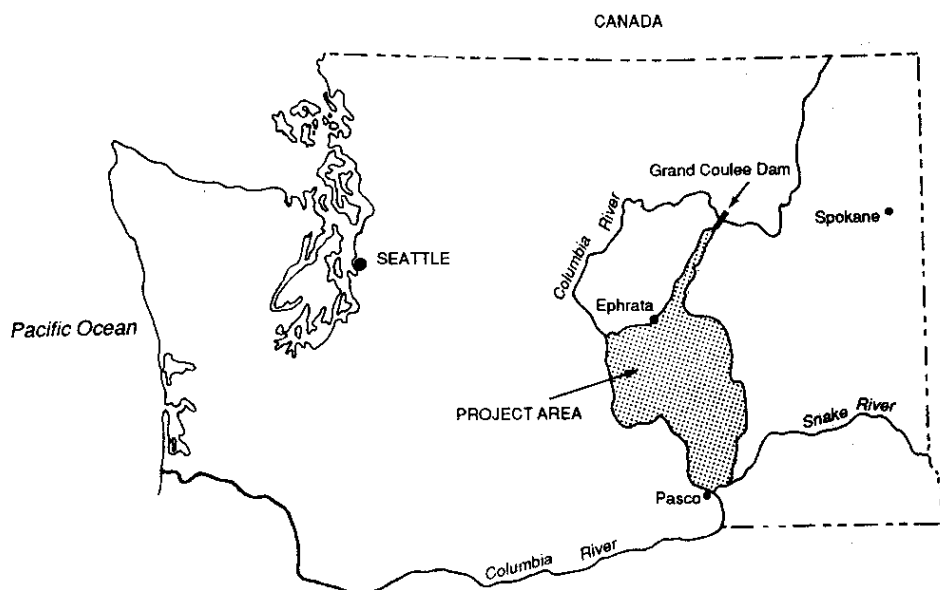
Water allocated to irrigation does not contribute to power generation as it is withdrawn from the reservoir and lifted 280 feet (85 meters) to the top of the escarpment bordering the reservoir without passing through the turbines to the river below. This means that there is no direct competition between releases for power generation and irrigation demands, as the two can operate largely independently.

Physical Environment

Location. The CBP lies in the east central portion of Washington State, in the United States of America, at about 47 degrees north latitude (Figure 5.2). The elevation of the command area varies from 1,400 feet (430 meters) in the upper end of the scheme to about 500 feet (150 meters) in the lower end. The service area begins 45 miles (75 kilometers) south and slightly west of Grand Coulee Dam, spanning about 80 miles (130 kilometers) in a north/south direction and roughly 50 miles (80 kilometers) east to west (Figure 5.3). About half of this area is classed as irrigable, the remainder being rough and unsuitable for irrigation. Irrigated areas are thus separated by uncultivated lands and spread out over a large area.

Climate. The climate in the Columbia Basin is an arid continental type; hot in summer, cold in winter, and extremely dry. The warmest month, August, has an average maximum temperature of 86.4 degrees F (30.2 degrees C) and an average minimum temperature of 52.6 degrees F (11.4 degrees C), while the coldest month, December, has an average daily minimum temperature of

Figure 5.2. Columbia Basin Project in Washington State, U.S.A.



23.6 degrees F (-4.7 degrees C) and a maximum of 37.6 degrees F (3.1 degrees C). Average monthly maximum and minimum temperatures are shown in Table 5.1

Located in the rain shadow of the Cascade Mountains, precipitation ranges from 6 inches (150 millimeters) in the southwestern part of the service area to around 10 inches (250 millimeters) in the northeastern highlands. Average monthly precipitation data for the center of the command area are shown in Table 5.1. It is noted that the amount of rainfall received during the irrigation season, which extends from March to October is extremely small, comprising 3.65 inches (93 millimeters) or 56 percent of the annual total. Minimum values for the year are recorded for the months of July and August — the heart of the growing season — when temperatures are at their maximum values for the year.

Potential evapotranspiration (PET), by contrast, totals 37.09 inches (942 millimeters) for the year, with 93 percent of the annual total occurring during the March-October period. The result is that rainfall supplies just 9.3 percent of the growing season PET requirement in the Basin, and only 2 or 3 percent of the requirement during the peak demand months of July and August. Rainfall is thus a relatively minor factor in meeting crop water requirements.

Relief. As noted above, the project area drops 900 feet (275 meters) from the upper end to the lower, a fall of about 11 feet per mile (2.1 meters per kilometer), or an average slope of about 0.2 percent. This relatively large gradient has several implications for the design and operation of the system. First, it allows the easy inclusion of free-flowing water measurement structures in the design, as the head loss they cause does not create design difficulties. Second, it provides ample opportunity for reusing drainage water. In fact, the southernmost district of the three districts making up the system is supplied largely by recaptured drainage water from the two higher

Figure 5.3. Columbia Basin Project.

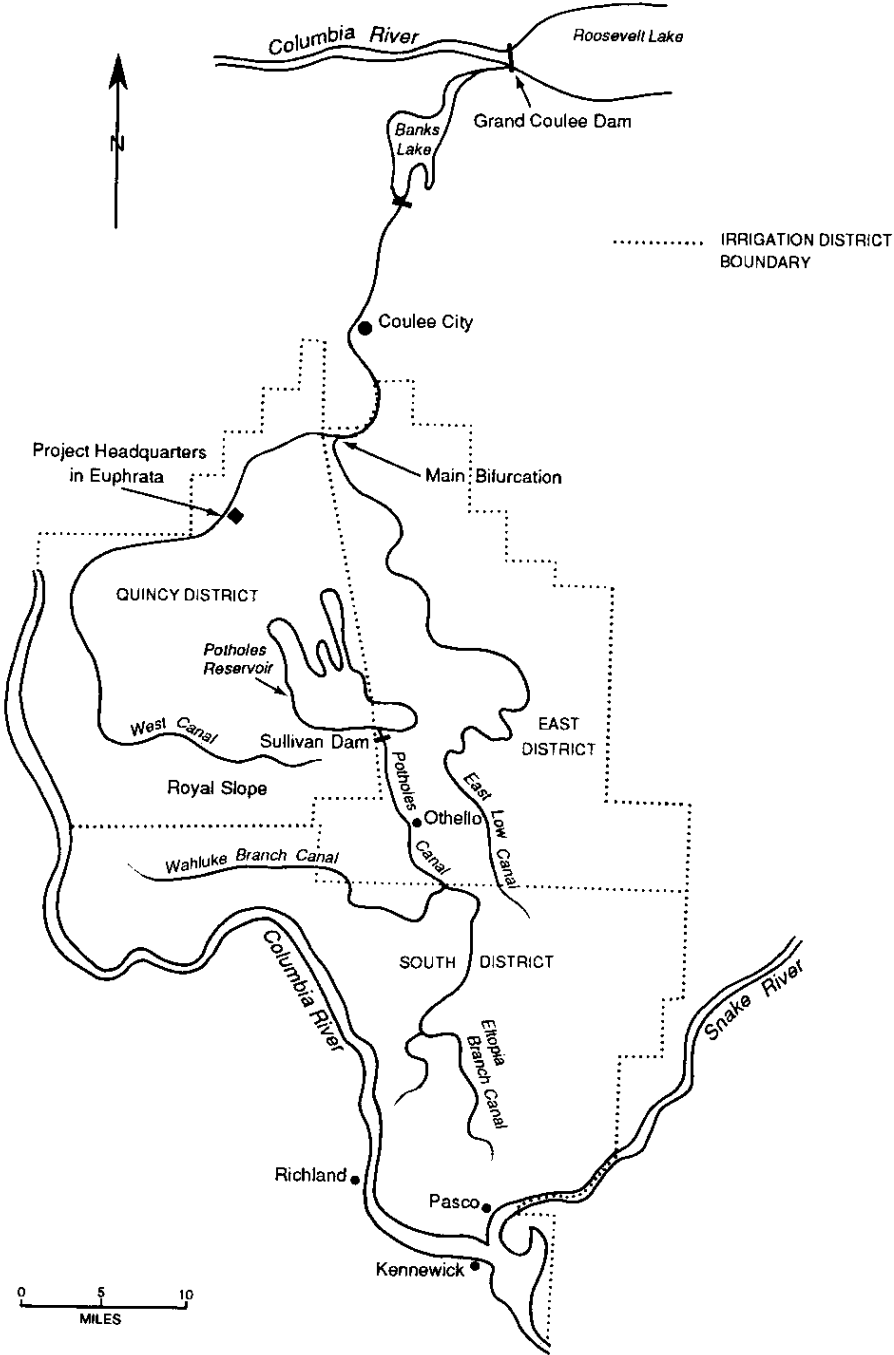


Table 5.1. Average monthly temperatures, rainfall and potential evapotranspiration rates for the Columbia River Basin Project.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Daily maximum ^a temperature (°F)	38.8	44.3	55.2	63.6	71.7	77.4	85.3	86.4	75.8	62.9	49.2	37.6	
Daily minimum ^a temperature (°F)	24.3	28.8	34.2	36.8	48.4	48.9	51.9	52.6	45.5	36.1	32.0	23.6	
Precipitation ^b (PPT) (inches)	0.60	0.66	0.82	0.46	0.63	0.44	0.21	0.11	0.56	0.42	0.86	0.77	6.54
PET ^c (inches)	0.61	0.98	2.33	3.88	5.41	6.57	7.77	6.90	4.24	2.30	0.95	0.52	42.4
PPT/PET	0.98	0.67	0.35	0.12	0.12	0.07	0.03	0.02	0.13	0.18	0.90	1.49	

Note: Bold type denotes the cropping season, which runs from March through October.

^aMaximum and minimum temperature figures are based on an average of 5 years of daily temperature data (1980-1984) from the Washington State University Experiment Station at Prosser, near Pasco, Washington.

^bPrecipitation figures are based on an 8-year average (1981-1988) of data collected by the United States Bureau of Reclamation (USBR) at O'Sullivan Dam (Podholes Reservoir) located in the center of the project area.

^cPotential Evapotranspiration (PET) based on estimated incoming solar radiation and average monthly temperature, after Hargreaves and Samani (1986).

elevation districts. Third, it results in the need for drop structures in the major canals, providing opportunity for profitable small-scale hydropower generation within the project.

Irrigation Water Supply, Delivery, and Application

Water Rights and Withdrawals. The granting of water rights in the United States is a state responsibility. Permits and certificates conferring rights for the CBP are issued by the Washington State Department of Ecology and are held by the United States Bureau of Reclamation (USBR). Water rights are extended to the irrigation districts through repayment contracts between USBR and the districts. Farmers are linked to these rights at the district level through membership in the district and through ownership of land in the district service area, as recorded on land plats.

Since 1985, when the irrigated area stabilized at around 560,000 acres (227,000 hectares), withdrawals have been running about 2.6 million acre-feet (3.2 billion cubic meters) annually, just under the quantity allowed by the certificate of right. These withdrawals comprise just 3.3 percent of the 80 million acre-feet of water which flows down the Columbia past this point each year.

Physical Facilities. The irrigation system serving the CBP can be divided into a supply system, a conveyance and delivery system, and, at the farm level, a distribution and application system. Each component has both physical and management components. A brief description of project physical works is provided below.

The **supply system** comprises the Grand Coulee Dam and the FDR Lake behind it (Figure 5.3) operated by the Bureau of Reclamation. Twelve large pumps lift water 280 feet (85 meters) to the top of the escarpment bordering the river channel. The **conveyance and delivery** system comprises a short (1.6-mile) feeder canal, a second small balancing reservoir, and a second length of main canal which conveys water some 21 miles to a bifurcation point where the main canal divides into the 88-mile long West Canal, serving Quincy Irrigation District, and the 87-mile long East Low Canal, which serves principally the East Irrigation District. Below the bifurcation, the respective irrigation districts assume responsibility. Districts handle distribution of water to individual farmers from their primary canals and a network of branch canals and laterals totalling 2,026 miles (3,268 kilometers) in length across all three districts.

In the center of the project area is a 511,700 acre-foot reservoir¹³ which captures some natural drainage, but its principal source is return-flow and drainage water from the surrounding irrigated area, which comprise about 70 percent of annual withdrawals from the reservoir. The third district in the CBP, the South Irrigation District, receives the bulk of its water supply from this reservoir.

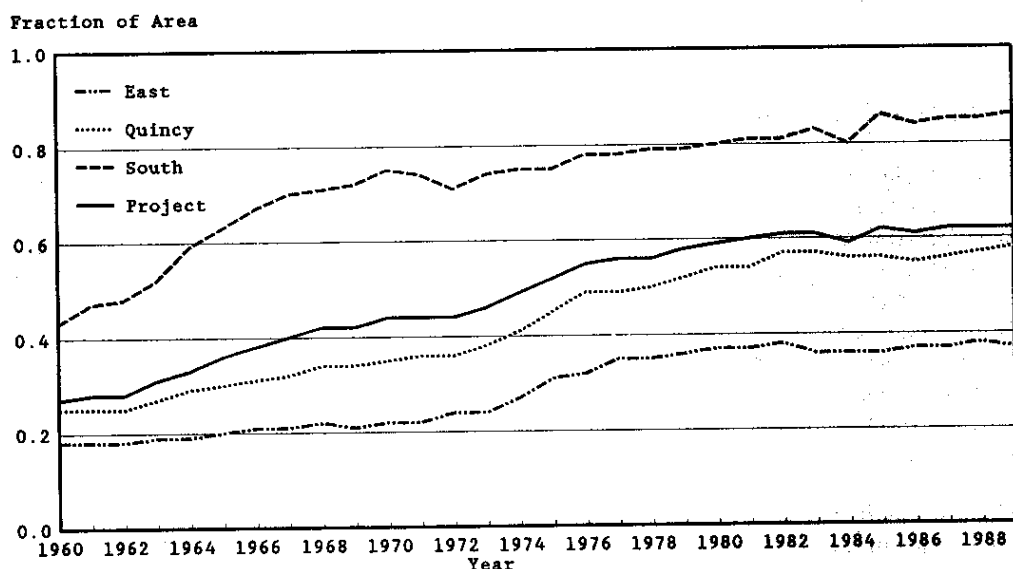
Once water is delivered to the farm turnout, it is typically carried in an earthen channel to a sump where it is pumped into a sprinkler system or led to furrows for surface **application**. In 1959, the first year for which data are available, about three quarters of the system's irrigated area was surface irrigated. By 1989 two thirds of the area was under sprinkler irrigation and only one third remained surface irrigated. Figure 5.4 shows the rate of sprinkler adoption in the three districts.

Water Management Procedures

The basic water management procedures used by the Bureau have been continued by the districts after management transfer. The scheduling process used in the project is referred to by local

¹³ Active storage is 332,200 acre-feet (409.8 million cubic meters).

Figure 5.4. Growth of sprinkler irrigation, CBP, 1960-89.



Source: Columbia Basin Project, district-level data.

engineers as a "modified demand system."¹⁴ Deliveries are based on requests from users, subject to scheduling and supply constraints. Crop water requirements are not calculated by the districts, but individual farmers may base their water requests on their own scheduling calculations, those of a commercial irrigation scheduling service, or their own experience. Farmers may request deliveries up to the limit of their basic and supplemental allotments at the normal charging rate. Farmers may also order additional "excess" water at a higher rate.

To order water, a farmer leaves a four-by-five inch "water request" card at his turnout, with information on the delivery rate, start time, and duration of the water order. Ditch riders report all orders to the watermaster by 4:00 PM each day and the watermaster "calls in" with the orders to the district office immediately thereafter. By 4:30 PM the district office calls the Bureau project office and the project adjusts the gates in the main system so that adequate water will be available on the following day to fill orders. Main system gates are adjusted remotely. The morning following receipt of new delivery orders, ditch riders adjust lateral gates and turnouts to make their deliveries. There are roughly 100 to 120 farm turnouts per ditch rider and five to ten ditch riders per watermaster, depending on the distance which must be traveled. Watermaster sections are roughly 50,000 to 60,000 acres (20,000 to 24,000 hectares) in extent.

Maintenance work is now planned and executed by the districts and reported to the Bureau. No O&M manuals are used by the Bureau or the districts. New staff are trained on an apprenticeship basis working with senior watermasters and ditch riders.

No water is delivered to a farmer for a new cultivation season until he pays the base water charge to his district. Supplemental and extra water charges may be paid during the season but must be paid off prior to the following irrigation season. Fees are charged by the acre (not by the

¹⁴ This system is sometimes called an arranged demand system in the irrigation literature.

acre-foot) so farmers pay the same base rate regardless of the land class, though they receive different amounts of water as their base allotment. Monthly water and financial statements for each farm are kept by the district.

Settlement Patterns and Policies

In the 1920s, just prior to construction of the Grand Coulee Dam, 90 percent of the land in the Columbia Basin was privately owned by early settlers and homesteaders. Most of the active farmland was used for dryland wheat production but there were large tracts of fallow farmland and sagebrush as well.

With the development of the irrigation project, a land ceiling was imposed limiting farm units to between 10 and 160 acres (4.0 and 64.7 hectares) depending on land quality and topography. The intention was to settle large numbers of new farmer families on the land to be subdivided and irrigated. Subsequently, the settlement goals of the project shifted toward providing fewer but more productive farms and offering settlement opportunities for veterans of World War II. Those which did settle in the Columbia Basin Project were generally well-educated, experienced in farming, above-average in wealth, and commercially oriented. They were farmers by choice in a booming postwar economy, a far cry from the earlier depression-era concept of masses of "buckboard pioneers" who would rush in to settle project lands.

Despite their typical independence, Columbia Basin farmers are accustomed to being involved in a variety of social institutions, such as soil and water conservation districts, weed control districts, volunteer fire departments, 4-H Clubs,¹⁵ and civic associations of various sorts. Local government units and county planning commissions developed rapidly during settlement. Among farm families, there was a strong tradition of group action to provide collective goods, such as fire protection, providing a solid base of experience for the organization and operation of irrigation districts later on.

In contrast to the situation of increasingly fragmented landholdings which is common in developing countries, farm sizes in the Columbia Basin have increased over time. Average farm sizes today are in the range of 160 to 240 acres (64.7 to 97 hectares). Roughly 60 percent of farm units are operated by owners and 40 percent by renters.

Agriculture

Since the inception of the project in the early 1950s, four major types of crops have comprised at least 75 percent of the total irrigated area in the Columbia Basin and have contributed 70 percent of the total returns to crop production in the area (see Table 5.2). These crop groups include potatoes, vegetables (for processing and fresh-market sales), hay and silage, and grains (wheat, barley, cereals and feed grain). In addition, fruit crops though representing only 6 percent of the total irrigated area provided 20 percent of total returns in 1985. Irrigated pastureland has consistently remained between 2 percent and 5 percent of total irrigated area since 1955, contributing less than 2 percent to total crop returns.

The cropping pattern across the CBP is clearly complex with a mixture of both high-value and low-value crops. Within this overall pattern, most farmers practice a multi-year rotation on their own farms. Profitability drives the farmers' choice in crop decisions, and cropping-pattern

¹⁵ Clubs for rural youth which teach farm-related skills.

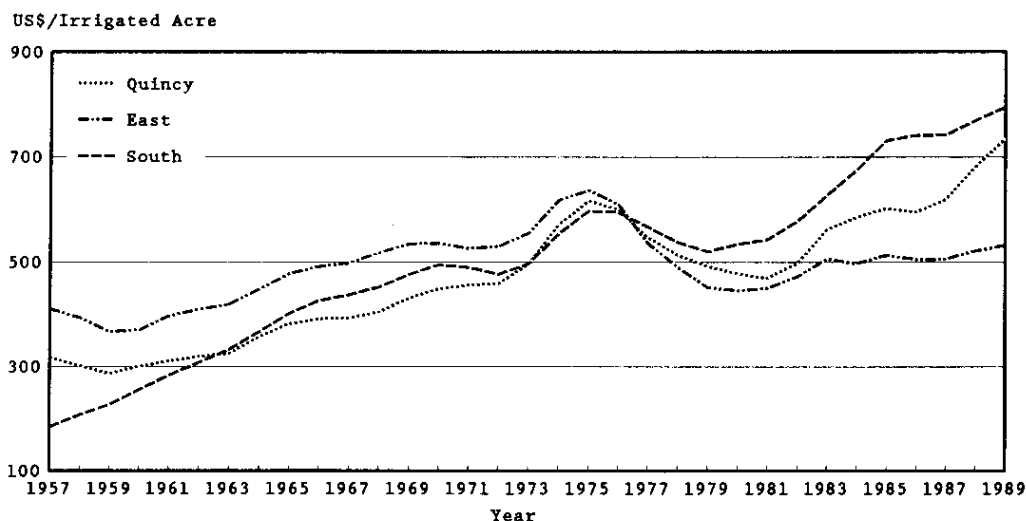
Table 5.2. Irrigated area and gross value of crop production, Columbia Basin Project (CBP), 1955-89.

Year	1955-64		1965-74		1975-84		1985-89	
	% of total irrigated area	% of total value of production	% of total irrigated area	% of total value of production	% of total irrigated area	% of total value of production	% of total irrigated area	% of total value of production
<i>Type of crop</i>								
Hay and silage	26.80	19.38	35.41	23.20	28.89	20.77	28.83	17.10
Vegetable	17.38	17.44	8.47	7.10	11.05	13.61	13.72	16.89
Grain	15.62	11.74	16.21	9.47	25.57	15.66	18.88	8.48
Seed	9.51	7.40	6.71	4.97	6.44	5.52	6.95	5.98
Potatoes	8.44	20.08	9.47	26.55	7.06	21.97	8.83	24.06
Sugar beets	6.21	15.25	8.80	16.78	3.48	4.64	0.00	0.00
Feed grain	4.75	3.59	3.95	2.90	9.11	6.74	8.34	4.04
Irrigated pasture	4.30	1.81	5.13	1.12	3.44	0.72	3.18	0.49
Specialty	0.65	1.16	1.48	2.38	0.86	2.09	1.53	3.02
Fruit	0.38	0.56	1.10	2.22	2.82	7.02	5.93	18.64

Source: Crop Production Reports for CBP, U.S. Bureau of Reclamation.

shifts have resulted in steadily rising total value of output in all the three CBP districts as shown in Figure 5.5.¹⁶ For the system as a whole, annual gross value of output per acre more than doubled, in real terms, between 1960 and 1989, from US\$356 to US\$828 (1982 prices). This suggests, overall, a system which adapts well to changing external conditions and supports the notion that, at least in a financial sense, the system is sustainable.

Figure 5.5. Average value of total crop production per acre, Columbia Basin Project (CBP), 1960–89 (3-year moving average in constant 1982 prices).



Sources: Crop Production Reports for CBP, U.S. Bureau of Reclamation; *Economic Report of the President*, President of the United States (Washington, D.C.: U.S. Government Printing Office, 1991).

Note: Prices adjusted by index of prices received by farmers in the U.S.A.

IRRIGATION INSTITUTIONS

U.S. Bureau of Reclamation

The U.S. Bureau of Reclamation (USBR) was established by the Reclamation Act of 1902 and charged with the mission of "reclaiming" the arid lands of the western United States for farming through the provision of irrigation. The Bureau was originally conceived as a construction and development agency and had an ambitious agenda for the design and construction of large dams, river basin projects, and irrigation systems. Because of the policy objective of settling barren and sparsely populated land in the West, costs for these expensive projects were primarily borne by federal taxpayers and by hydroelectricity revenues. Typically, farmers were given 50 years to repay

¹⁶ The sharp temporary increase peaking in 1974 is probably due to the spike in world wheat prices which occurred in that year.

a minor share of full construction costs and paid very low rates for water (Reisner 1987). Also, because of this policy orientation and the economic rents involved, the Bureau supported numerous laws aimed at limiting the size of irrigated farms and preventing speculative buying and selling of land brought under irrigation over the first several decades of its existence.

The Reclamation Act established that the USBR would transfer management responsibility and authority for system facilities to irrigation districts, once construction was completed. It also established that farmers would be obligated to repay some negotiated portion of construction costs and all costs associated with project operation.

The U.S. Bureau of Reclamation shares a number of features with water resources departments and ministries in developing countries. Its mandate for irrigation development is underlain by strong social-welfare considerations. Traditionally it has been principally a construction agency, with little enthusiasm for handling operation and maintenance (O&M), and it has channeled heavy public subsidies on irrigation water to farmers. However, the Bureau is differentiated from most of its counterparts in developing countries by its mandate to help create users' irrigation districts and transfer management to them, to negotiate construction repayment schedules, and to levy O&M fees on users prior to the transfer, and its record of success in doing these.

Irrigation Districts

Irrigation districts have long been the predominant institution for managing irrigation systems in the American West. Irrigation districts are quasi-municipal corporations, established under state law for the purpose of supplying and delivering water to irrigable land. They are generally untaxed nonprofit corporations constituted by water users and registered with state governments. Water rights are attached to districts through a process of granting and certification by state governments.

Water users are attached to the districts through their relationship to the irrigable land within the irrigation district. Districts are normally governed by a board which is elected by a vote open to all landholders in the district. Districts are vested with authority for planning and managing irrigation operations and maintenance, raising resources to fully cover the annual costs of operations and maintenance and of capital replacement, and applying sanctions against members who violate district rules or fail to pay water fees. Sanctions may include cessation of water deliveries or seizure of farms of violators.

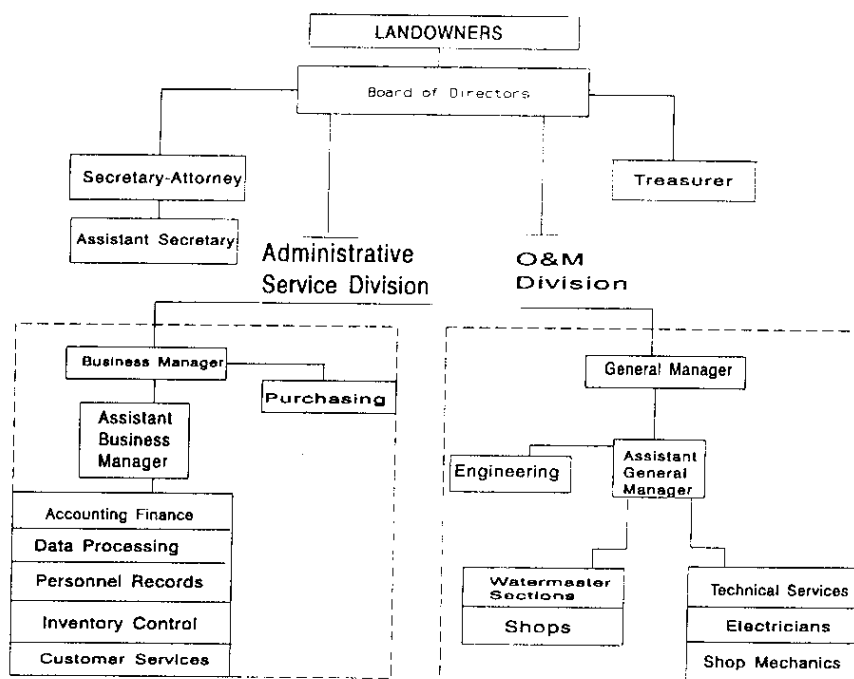
The three irrigation districts comprising the Columbia Basin Project, the Quincy, East, and South Districts, were created in 1939, two years before completion of Grand Coulee Dam and 13 years before water began flowing through the irrigation system. Formation of the districts initiated an extended period of negotiations over repayment contracts for the project. Each district includes between 2,000 and 2,500 land owners and is governed by a board of directors elected by its members. A district is divided into several sections, usually numbering between five and seven, with each section electing a director who sits on the board. Each director must own land in the district, although the land does not have to be developed or irrigated. Board members are elected for overlapping three-year terms and generally run unopposed. They are not remunerated. Incentives for their participation include personal satisfaction, opportunities for expense-paid travel, a stronger political voice, and social prestige. Boards have a wide range of concerns but some of the most significant are financial — raising sufficient revenue to pay for O&M and capital replacement while seeking to keep O&M costs as low as possible.

District management is in the hands of a full-time professional staff. District managers, who are responsible for the day-to-day operation of the districts, are engineers recruited through open notices throughout the West. They are selected by the board of directors and are responsible to it.

Irrigation district management is a well-established career path in the American West and positions are announced in various publications.

Figure 5.6 shows the organizational set-up of the Quincy District and Figure 5.7 that of the other two districts, East District and South District. A district has two main divisions, an O&M Division and an Administrative Service Division. The O&M Division is run by the General Manager and is staffed by watermasters, ditch riders, and other supporting positions. The Administrative Service Division handles budgeting, accounts, data processing, personnel records, inventory control and miscellaneous customer services to farmers, such as providing information or assistance with forms and regulations. Since districts are legally established by the state government, the state requires that their books be audited annually. The auditors are independent certified public accountants.

Figure 5.6. Organizational structure of Quincy District, Columbia Basin Project.

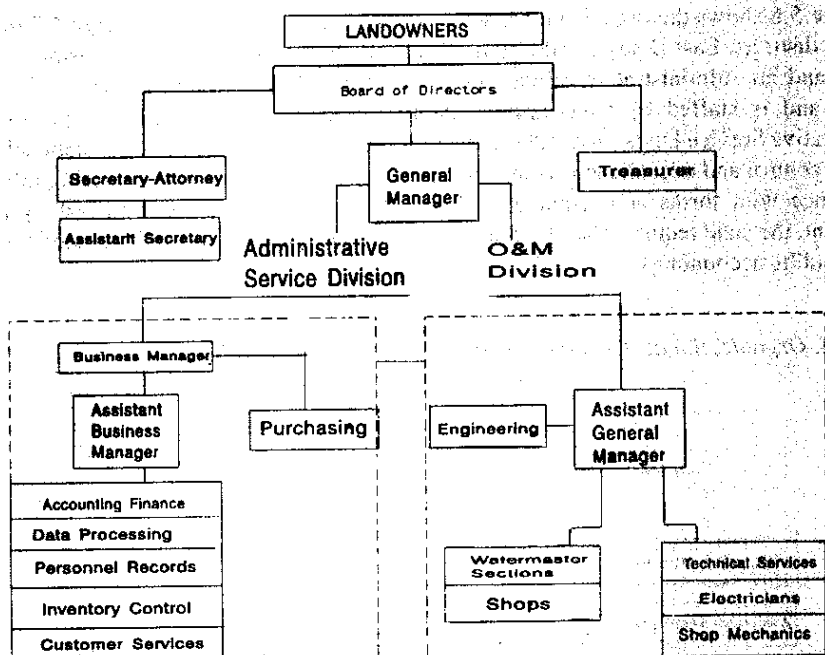


Source: District-level data, CBP.

Relationship between the Bureau and the Districts

Relations between the USBR and the irrigation districts are defined by public law and through negotiations leading to legally binding contracts and agreements. Because of the size, wealth and political influence of irrigation districts in the American West, the Bureau and districts generally relate to each other as political equals, regularly negotiate solutions to problematic issues, and periodically sue one another when agreement is not reached. This contrasts sharply with the

Figure 5.7. Organizational Structure of East and South Districts, Columbia Basin Project.



Source: District-level data, CBP.

situation in many developing countries, where the irrigation agency is clearly in a superior position to irrigators' associations. The official relationship between the Bureau and an irrigation district is established by a "repayment contract," which is an obligation attached to irrigable land lying within the district, and associated landowners, regardless of whether or not available project water is used by the individual.

A common situation in developing countries is for governments to attempt to induce farmers to take on responsibility for managing all or parts of irrigation systems, even though they may not receive concomitant authority for making necessary decisions. Governments first work to organize groups of farmers into formal water users' organizations, after which management is handed over to them according to terms set by the government. In the Columbia Basin, by contrast, there was little of this type of consciousness-raising and inducement of farmer participation. This would seem to stem from the fact that farmers were already experienced in establishing and managing local organizations for other purposes, were on an equivalent legal and political footing with the Bureau, and were already paying for O&M services and thus had an incentive to assume management responsibility to keep down the costs of O&M and make management more "customer-oriented." The result is a trio of strong and well-organized districts, which have their own legal representation, capable of exerting considerable political pressure on the Bureau.

MANAGEMENT TRANSFER

Motivation for Transfer

Farmer perspectives. Since their creation, the districts knew that responsibility for O&M would eventually fall on them. So the districts were interested not in trying to prevent management transfer, which they knew was inevitable, but in trying to get the best terms possible. According to district officers and lawyers, the farmers' primary interests were in obtaining more local control over water allocation, water fee structures, O&M expenditures, and drainageways and minimizing water charges.

The following are quotes from a letter to the US Department of the Interior written in 1964 by a farmer leader in the project (not without some hyperbole, perhaps):

"We out here on the project feel that the most of the Bureau employees... are only interested in having a permanent job....They get their paychecks from the government, but we pay the bill. They should be working for us."

"...most of the Bureau people are just interested in going by the book and getting a regular paycheck. The last thing they think about is how what they're doing affects the farmer."

"We don't want the Bureau spending our O&M money either, just to get things the way they want them — if the turnout is too low — and lots of them are — then they should be fixed with construction money."

"Mostly, we want to run our own show, to live with our own mistakes, and not repeat them, and profit by our own actions."

One clear theme in these statements and in the views of farmers is the assertion of the right to local control over a resource for which they are paying, with the underlying assumption that local management would be both cheaper and more responsive.

Bureau perspectives. A response to the above letter from a representative of the U.S. Department of the Interior contained the following statements:

"We would like to reiterate...that the policy of this Department, with the full support of the Congress, has been to maximize local operation and maintenance of federally constructed irrigation facilities....the success of this policy can be assured only if all parties concerned agree on terms and conditions under which the operation and maintenance is to be transferred, and these terms and conditions must be such that the interests of both the United States and the water users are protected."

"...the Commissioner of Reclamation...assures me that he is anxious to work out terms and conditions under which the operation and maintenance can be transferred."

A clear theme implicit in the above statements is the government's acknowledgement that the districts should take over management and its fundamental acceptance of a process of negotiation with the districts as a means for evolving a workable relationship between the two. The farmers didn't like the "red tape" of government management and the Bureau didn't want the headaches of dealing with thousands of individual farmers.

Transfer Process

A protracted period of negotiations began in the early 1960s among the three districts and with the Bureau, and intra-district agreement was often more difficult to achieve than agreement between the districts and the Bureau. Despite the fact that both the Bureau and the districts wanted the transfer to proceed, discussions were sometimes heated. The Bureau often took the initiative to draft plans and agreements and conduct cost studies, and this was sometimes resisted by the farmers. It was reported that in one meeting in 1965, a district official stated that "they [the districts], and not the bureau, will be taking the initiative to achieve the take-over" (Orinello Outlook 1965).

Over a period of about five years, the districts gradually came to agreement over water, cost allocation and works which should be (a) reserved by the Bureau, (b) managed jointly between districts, and (c) transferred to individual districts. Mutual concessions were made by districts regarding alignment of O&M responsibilities and apportionment of costs. Agreements accomplishing the transfer were signed in December 1968 and took effect on January 26, 1969. This was one of the largest management transfers the Bureau had undertaken.

Terms and Conditions of Transfer Agreements

It was the "care, operation and maintenance" of the irrigation system which was finally transferred to the Quincy, East, and South Irrigation Districts, and not ownership itself. The following are the more important terms and conditions which were agreed to.

District Rights

- The districts can determine basic and excess-water charges to farmers, although charges for the basic allocation remain related to land productivity classes.
- Districts can enter into water services contracts to supply excess water to farmers outside the districts. However, districts may not sell water rights since the transfer of water rights from one landholding to another is prohibited.
- The districts have rights of eminent domain and foreclosure on land. They are not liable for damages resulting from the storage, conveyance, seepage, overflow, and discharge of water either to other districts or to individuals.
- Districts are allowed to purchase heavy equipment and supplies from the project with a ten-year payment schedule. This included such vehicles as tractors, road graders, and pickup trucks.
- The districts have the right to obtain revenues by developing power generation stations within the system or by other "miscellaneous" means. The right to generate power was considered as concessional by the Bureau, since the districts pay an extremely low, highly subsidized rate for the primary lifting of water from the FDR Reservoir.

District Responsibilities

- Districts must comply with the agreed construction repayment schedule, which includes partial repayment for drainage construction.
- Districts are responsible for all operations and maintenance for facilities used individually and jointly by the districts, in accordance with Bureau standards of performance and financial viability.
- Districts are responsible for paying their mutually agreed proportions of the recurrent costs of special "reserved works" which were retained for management by the Bureau.
- Districts are responsible for making annual payments into a capital replacement reserve fund at a rate equal to 30 percent of five-year average annual O&M costs. They must eventually replace deteriorated facilities with this fund.
- Districts must report maintenance plans annually, in advance, to the Bureau.

Bureau Rights

- The Bureau has the right to resume direct management of the system if the districts failed to make their construction repayments, pay for the O&M of reserved works, or properly maintain the system.
- Bureau staff affected by the management change would be transferred either to other Bureau projects (as was the case with most construction staff) or to the districts themselves (as was the case with most O&M staff). Most of the initially employed district management staff were former Bureau, CBP employees.
- Salaries and benefits of transferred bureau staff members such as ditch riders and watermasters remained at the levels prevailing before transfer. Federal retirement plans for transferred staff were cashed in or suspended and new district retirement plans were started, although without seniority.

Bureau Responsibilities

- The Bureau has responsibility to manage the "reserved works" which serve the entire project. These included the Grand Coulee Pumping Plant, Banks Lake, the Main Canal, and Potholes Reservoir.
- The Bureau conducts operation and maintenance reviews (or "examinations") every three years to audit O&M performance standards of the districts and make recommendations for improvements.
- The Bureau retains ownership of the facilities operated by the districts at least until completion of repayment or replacement of facilities by the districts. However, under current law, wholesale transfer of ownership of system facilities to the districts would require an act of Congress. The districts favor the retention of legal title for facilities by the Bureau, since they believe this protects them from certain legal liabilities.

- The Bureau must report, in advance, its maintenance and repair plans for its reserved works to the districts on an annual basis.
- The government will acquire needed rights-of-way for water movement within the project area.

Management Changes since the Transfer

The Bureau. Since the transfer, the Bureau has drastically curtailed its direct O&M activities and taken on new roles in environmental regulation and land management. About 210 Bureau project staff positions, mostly in O&M, were abolished by the transfer and 80 to 90 percent of Bureau staff occupying these positions were transferred to the districts. Others retired or were transferred to other Bureau projects (see Table 5.3).

Today there are only seven Bureau positions in O&M, compared with 12 handling land and environmental regulation and water rights. One of these positions is a new one, established to handle coordination between the project and the district offices for operation and maintenance activities, water service contracts, land and water rights, licenses and permits, and so on.

The Districts. Just prior to management transfer, each of the districts had only a handful of staff. South District, for example, had a manager, an administrative assistant, and a bookkeeper. The first district managers were not transferred from the CBP but were openly recruited by district boards. However, all three new managers had previous district or Bureau experience. Most of the staff from the level of watermaster and below were transferred from the Bureau to the districts.

Staff densities in the three districts average about one person per 2,000 acres (809 ha). Since transfer, staff levels in each of these districts are reported to have declined by 10 to 15 staff members. Districts can and do fire staff. Quincy District has released about five staff members in the past two years, even though ditch riders and O&M service staff are unionized.

District O&M personnel handle all water allocation functions down to the farm turnout with little farmer interference reported. Quincy District reports about 6 cases a year where farmers cut locks on their turnouts to change settings. This is normally done when a farmer wants to stop the flow of water quickly, as when a center pivot breaks down. Districts have the power to stop delivery of water in the event of nonpayment of water assessments by farmers and have exercised this power rigorously. For example, since management transfer, Quincy District has foreclosed and sold more than 20 landholdings due to nonpayment of water charges.

All three districts have established excess-water-use policies. Owing to increasing concern about possible damage to lands and drainageways resulting from over-irrigation, the districts have raised the charges for use of water in excess of the base allotment. Because of the high thresholds involved, these graduated charging schemes are largely symbolic at present, but they do suggest an area of concern and a willingness to act.¹⁷

Each of the districts is involved in granting water service contracts to landholdings not included in the irrigation district. Districts argue that the water used for this purpose is mostly derived from existing allocations to the districts for waste, seepage, return flows, or water draining to adjoining lands. The regular water service contract normally guarantees allotments for a limited time period at the same O&M-assessment level applying to district members, together with a partial

¹⁷ Some California water districts have implemented much steeper rate schedules which do have practical impacts on a wider range of irrigators.

construction repayment requirement. A second class of interruptible contracts does not *guarantee* water delivery and the fee includes only a partial O&M assessment.

Table 5.3 Number of Bureau of Reclamation staff assigned to the Columbia Basin Project, by division, 1961–1985.

Year	Power	Irrigation and Land	Engineering and Construction	Administration	Project Management	Full-time, Regular Total
1961	329	277	119	85	7	817
1962						824
1963	316	300	133	83	7	839
1964						
1965	273	300	159	82	10	824
1966						829
1967 ^a	295	309	160	75	11	850
1968	299	301	163	67	11	841
1969	297	103	150	53	9	612
1970	0	92	121	27	7	247
1971	0	92	98	23	8	221
1972	0	89	91	19	9	108
1973	0	28	147	21	8	204
1974	0	28	132	21	7	188
1975	0	28	136	22	7	193
1976	0	28	112	21	8	169
1977	0	26	114	20	8	168
1978	0					
1979	0	24	55	18	4	101
1980	0	25	82	20	6	133
1981	0	26	77	18	6	127
1982	0	24	72	16	5	117
1983	0	22	61	15	5	103
1984	0					
1985	0	22	43	13	5	83

Source: U.S. Bureau of Reclamation data.

Note: Data are missing for the years 1962, 1964, 1966, 1978 and 1984.

^a In 1967, staff reporting shifted from December to January.

Districts contract with the Bureau for some management functions which fall within their area of responsibility under the transfer contract agreements. East District, for example, contracts with the Bureau to manage the district main canal, although the other two districts handle main canal operations themselves. The main computer and telemetry receiver for the automatic data acquisition and control system bought by the districts has been installed in the Bureau office in Ephrata rather than in one of the district offices, and Bureau staff members monitor system status and manage this data system. This indicates the close working relationship which has evolved in the wake of the transfer.

District boards are continually looking for ways to keep water charges down. One strategy has been to raise revenue through secondary enterprises to cover part of the O&M cost and to supply reserve fund requirements. In 1980, the districts agreed on a joint power-development plan and have jointly developed seven hydroelectric power stations throughout the system. These facilities have been developed by municipal power and light companies which provided the US\$160 million financing and contracted to purchase the power produced. Districts receive two mills (two tenths of a US cent) per kilowatt hour currently, with the remainder of the districts' share being retained by the power companies to retire construction debt obligations. When these obligations are fully satisfied, the revenue to the districts from power production will increase sharply. Amortization schedules for the power installations range from 10 to 40 years.

Under the original repayment agreement of 1945, irrigation districts were charged 0.5 mill per kilowatt-hour (KWH) for water pumping costs at Grand Coulee. This rate continues in effect, despite the rise in summertime market value of power to about 17 mills per KWH. The Bureau is seeking to raise the rate charged to the districts to 0.95 mill per KWH, claiming that this is the cost of generating the power, and the issue is currently in court.

Surprisingly, district managers report that a sizeable number of project farmers still think that the districts are part of the Bureau of Reclamation. Only a minority of farmers generally attend district meetings. Despite this indication of some detachment, farmers generally appear to be satisfied with the performance of the irrigation districts. Matters of district policy and management are generally left to the board or managers. The districts have continued to successfully manage daily operation of this intensive, "arranged demand" management system since 1969, with the exception of one day — the day four inches of volcanic ash from Mount St. Helens fell on the project.

RESULTS OF THE TRANSFER

Data Sources

Data for this portion of the analysis were obtained principally from the Bureau of Reclamation office in Ephrata and from the three irrigation districts. Annual time series data were obtained on area irrigated,¹⁸ discharge at various points in the conveyance system, aggregate discharge at system turnouts, area under various water application technologies, area planted by crop, gross value of agricultural output by crop, revenues by source, expenditures by category, and personnel levels by function. Aggregate potential evapotranspiration (PET) data were computed from cropped area figures and multi-year average crop-specific PET values for sites within the project area obtained from Washington State University. Most data were available on an irrigation district

¹⁸ Area figures from USBR Water Distribution Reports often did not agree exactly with similar figures from the Crop Production Reports. For most purposes, figures from the Water Distribution Reports were used in the analysis.

basis, though the analysis is concentrated on the project as a whole. Periods of record vary, but for most variables a time series of 20 or 30 years is available.

Changes in Technology

It is the view of the district managers that adoption of innovative technologies such as hydraulic excavators, telemetry, and sprinkler irrigation was facilitated by management transfer. Their argument is that districts were more open to new ideas and technologies, more flexible, and able to make quicker decisions than was the Bureau.

This argument is easier to accept in the case of main-system operation and maintenance technologies than in the case of water-application technology. The widespread adoption of center-pivot sprinkler irrigation has been one of the most dramatic technological changes occurring in the project in the past 25 years. However, sprinkler systems are owned and operated by individual farmers and their adoption is driven more by financial factors, such as rising labor costs and the higher yields often obtained under sprinkler irrigation, than by the management mode of the irrigation system. Even in the case of the main system, it is difficult to know what would have happened had the Bureau continued to manage the scheme. At the very least, one can say that the adoption of new technology does not appear to have been hampered by the transfer of management responsibilities to districts, and may well have been accelerated.

Quality of Irrigation Service

One of the most important potential impacts of the transition to self-management is the effect on the quality of irrigation service to farmers. Quality of irrigation service can be defined in terms of three characteristics — adequacy of water supplied by the irrigation system, timeliness of the supplies, and equity of distribution across system subdivisions. In each case, a useful indicator must consist of a cardinal or ordinal measure and a means of standardizing the measure to allow comparison across units or over time. If qualitative judgements are to be made about the measure, then some standard is also required, along with rules for evaluating the indicator against the standard.

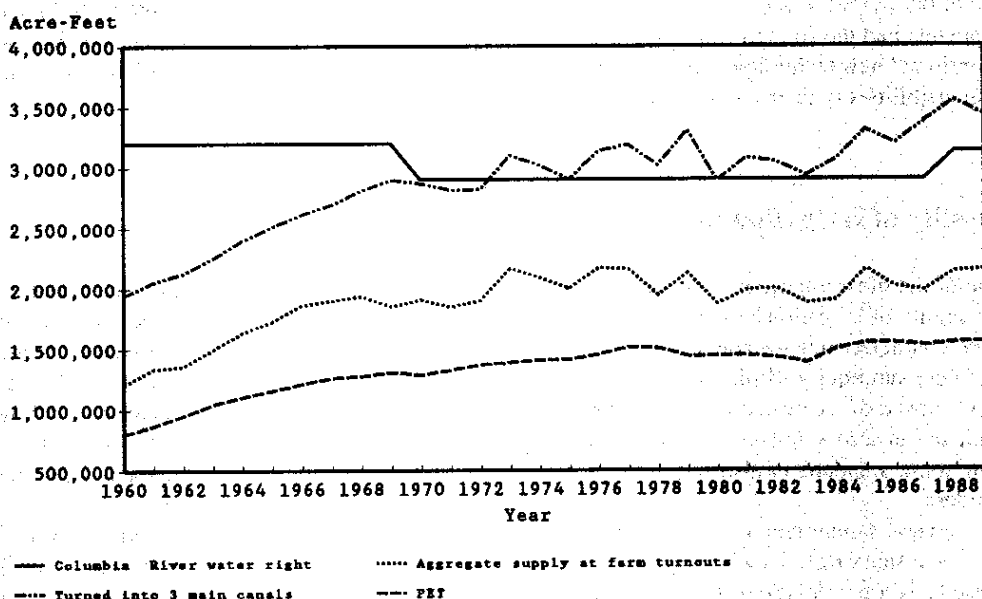
Several salient features of the CBP underlie the following analysis. First, the CBP is a water-surplus system. Both its water right and its main pumping capacity exceed current demand. Canal capacity is a potential constraint to increasing supplies, but has not been an active constraint in recent years. Second, the CBP is a demand-driven system. Farmers place orders for water, specified in terms of discharge, duration, and delivery date and the system delivers water, also specified in these terms.

Consequently, it is assumed here that farmers place orders for water based on the potential evapotranspiration (PET) requirements of their crops. PET is assumed to represent the expressed demand for water. Ideally, an evaluation like this would take place in two stages. First, the orders placed would be compared with crop water requirements to determine the appropriateness of the orders. Then, orders would be compared with actual deliveries to determine the system's effectiveness in meeting the farmer-specified demand for water. In this case, although information on individual orders and deliveries is available in district files, it was deemed too expensive and time consuming to sample, retrieve, and analyze it. As a result, a one-stage analysis was used employing the assumption that PET represents the approximate farmer demand for water.

Adequacy.

Figure 5.8 shows the quantity of water turned into the system's three main canals at the bifurcation and from the Potholes Reservoir, and the project water right at the Columbia River. The fact that supply exceeds the water right does not indicate a violation of the right, as the total includes Potholes water which consists largely of irrigation return flows. It is thus "counted twice" with respect to the withdrawal permit. The quantity turned into system main canals shows a steady increase with time as irrigated area expanded, until about 1973. It is roughly stable from then until 1985 when it again begins to rise. Figure 5.8 also shows the aggregate amount of water delivered to farm-level turnouts over time. This value too shows a steady rise until 1973, when it stabilizes at around 2 million acre-feet (2.5 billion cubic meters) and holds constant at that level until the end of the period. It does not show the pronounced rise in level that the main-canal supply does after 1985. Aggregate PET demand is less volatile, exhibiting steady growth throughout the period,¹⁹ but at a rate which declines with time.

Figure 5.8. Water diverted, delivered and required, CBP, 1960-89.

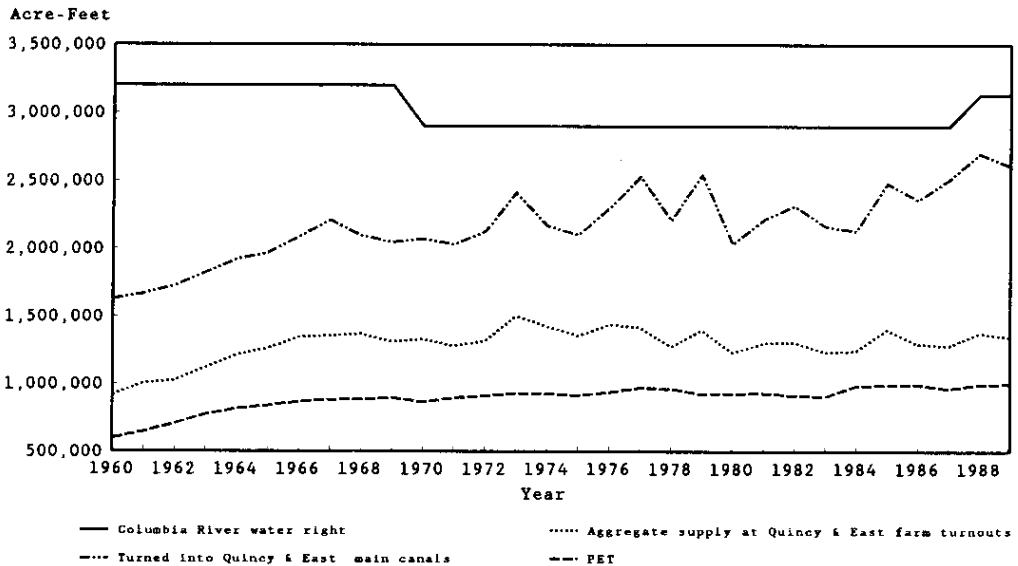


Sources: Water Distribution Reports for CBP, U.S. Bureau of Reclamation. PET calculated from data in James, Erpenbeck, Bassett, and Middleton, *Irrigation requirements for Washington — estimates and methodology* (Pullman: Washington State University, 1989), pp 6-13.

¹⁹ To some extent, this is an artifact of the computational procedure used, since longer-term average values of PET for particular crops are used in the computation. Year-to-year changes in aggregate water demand thus reflect variations in crop mix and total area irrigated only.

In Figure 5.9, data on supplies from Potholes Reservoir have been deleted so that the two supply curves and the demand line relate only to virgin water pumped from the Columbia. Now it is seen that water withdrawals have remained comfortably within the water right limit.²⁰ The maximum withdrawal, 2.7 million acre-feet (3.3 billion cubic meters), occurred in 1988, the year in which incremental area was added to the system and the water right was increased. Seen again in this figure is the steady divergence between main-canal supplies to the two districts and the aggregate deliveries to farm turnouts. This divergence will be explored further in the discussion of system efficiency.

Figure 5.9. Water diverted, delivered and required for Quincy and East Districts, CBP, 1960–89.



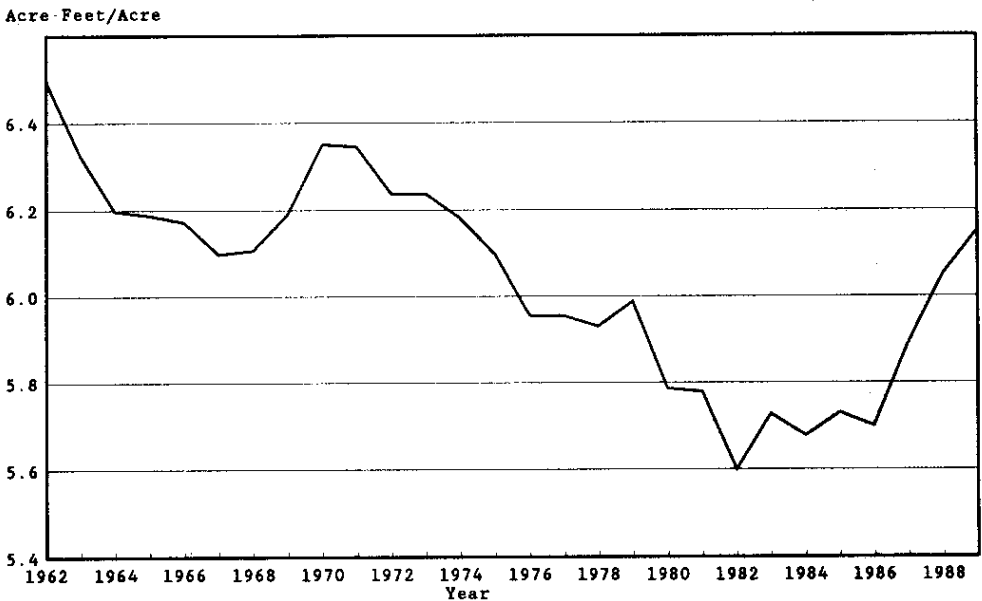
Sources: Water Distribution Reports for CBP, U.S. Bureau of Reclamation. PET calculated from data in James, Erpenbeck, Bassett, and Middleton, *Irrigation requirements for Washington - estimates and methodology* (Pullman: Washington State University, 1989), pp 6–13.

While the volume of water supplied was steadily growing, the area served was also expanding (see Figure 5.1). In order to understand what happened to water deliveries on a unit-area basis, it is necessary to standardize water volume by dividing by area served. When this is done for total aggregate supply at the heads of the three main canals, the result is shown in Figure 5.10. It is seen that the amount of water supplied to the three districts increased sharply in 1969 and 1970, the first two years of district management. In 1971, a steady decline from this peak of just over 6.3 acre,

²⁰ This assumes no net, year-to-year change in storage in Banks Lake, no net inflows to Banks Lake not lifted from the Columbia, and negligible conveyance losses between the pumping plant and the bifurcation.

feet/acre begins which continues for the next 15 years, ending at a value of around 5.7 acre, feet/acre, a drop of about 10 percent. In 1986, a puzzling and extremely rapid rise commences in the amount of water supplied to the three districts per unit area irrigated which lasts until the record ends in 1989. The implications of this rise will be explored later in the analysis.

Figure 5.10. Total water supply per acre, CBP, 1960–89 (3-year moving average).



Source: Water Distribution Reports for CBP, U.S. Bureau of Reclamation.

Note: Years shown on graph are final years in each 3-year period.

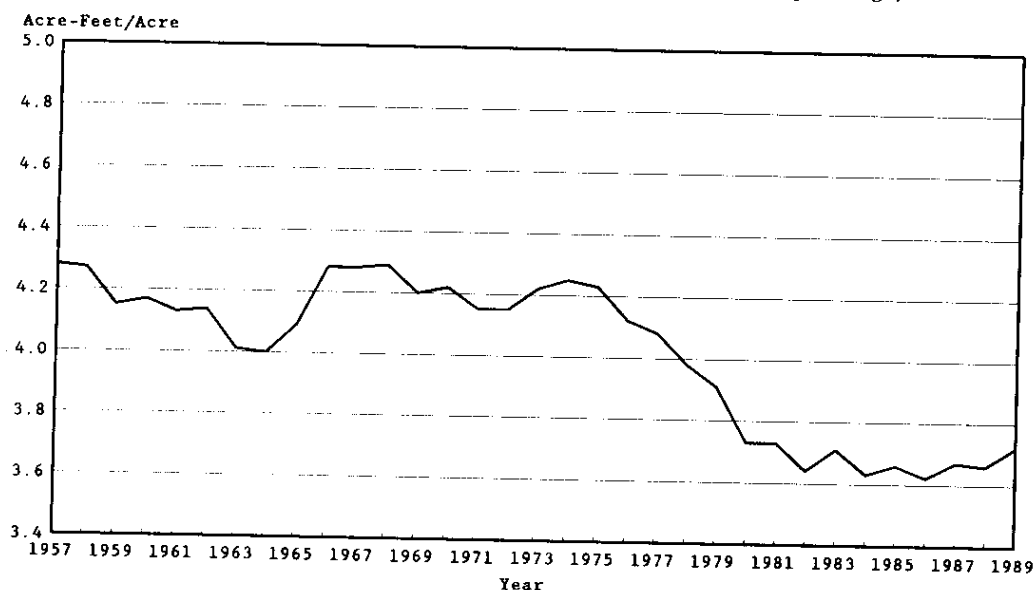
When aggregate supplies to turnouts are similarly put on a per-unit-area basis, it is apparent that water deliveries per unit area have declined continuously, from about 4.5 feet in the early 1950s to about 3.7 feet in the late 1980s (Figure 5.11). There is no obvious discontinuity in this trend associated with the 1969 transfer of management responsibility,²¹ indicating that the additional water ordered by the districts in the years immediately following the transfer did not reach farm turnouts and was lost in district distribution systems. The most pronounced decline in per-acre water deliveries to farm turnouts occurred during the 1970s, coinciding with the period of most rapid growth in area under sprinkler irrigation (Figure 5.4) and the decline may be related to the shift to more efficient application technology.

However, cropping patterns also changed during this time, and it is possible that a shift to less water-intensive crops may have reduced the aggregate crop demand for water. To examine this

²¹ The amount of water delivered to farm turnouts was actually less in 1969 and 1970 than in 1968, the last year of Bureau management.

possibility, crop weighted aggregate annual PET for the CBP was plotted as in Figure 5.12.²² The graph shows two distinct periods — a rising trend between 1955 and 1972 and a declining one from 1973 to the end of the period.²³ The second period can also be subdivided into a period of sharp decline from 1973 to 1981 and a period of relatively constant PET thereafter. The major drop between 1978 and 1979 is associated with the complete phasing out of sugar beet production, the most water-intensive crop grown in the basin, and its replacement with vegetables, one of the least water-intensive crops grown.

Figure 5.11. Total water delivery per acre, CBP, 1955–89 (3-year moving average).



Source: Water Distribution Reports for CBP, U.S. Bureau of Reclamation.

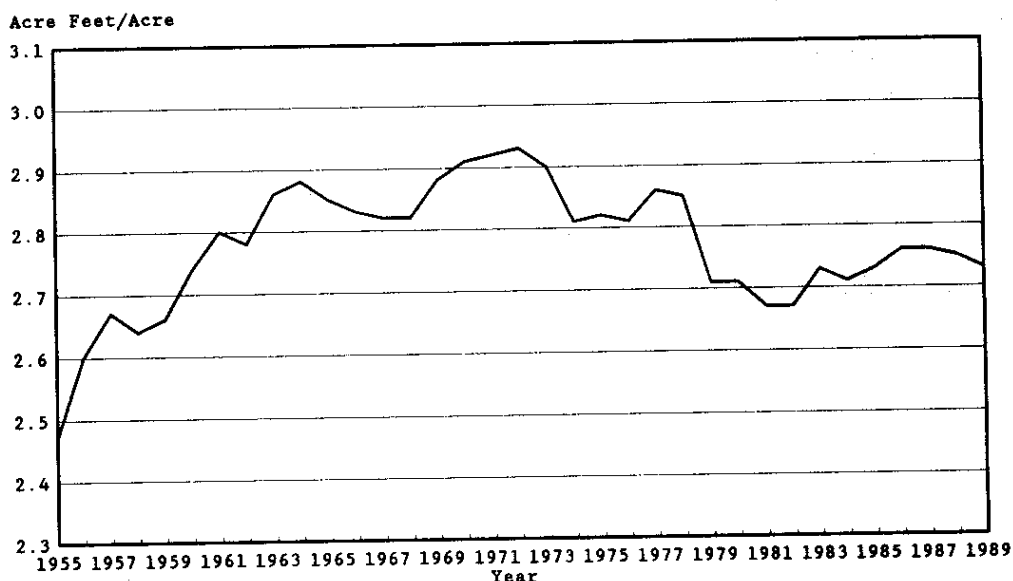
Note: Years shown on graph are final years in each 3-year period.

Between 1973 and 1981, the period of rapid decline, unit-area PET fell by 7.6 percent as a result of cropping pattern shifts, while water deliveries per unit area, shown in Figure 5.11, fell by 10.1 percent. This suggests that about three quarters of the reduction in farm demand for water during this period was a result of cropping pattern shifts, and only about one quarter resulted directly from increased water application efficiency occasioned by the shift to sprinkler irrigation. At the same time, it is likely that the introduction of the center pivots was instrumental in permitting farmers to make the shift to certain new crops because of their lower water application rates and more precise water control. The main water-saving effect of improved application technology thus appears to have operated indirectly during this period of rapid change.

²² Here and throughout this study, PET as reported is the net of effective precipitation. Because summertime effective precipitation in the CBP is very small, this modification makes little difference in practice.

²³ Changes in PET do not reflect changes in climatological demand, because a common set of average crop-specific PET demand figures are used for each year in the series.

Figure 5.12. Crop-weighted potential evapotranspiration for CBP, 1955–89.



Source: Computed from data in James, Erpenbeck, Bassett, and Middleton, *Irrigation requirements for Washington — estimates and methodology* (Pullman: Washington State University, 1989), pp 6–13.

Going one step further, the aggregate water supply at the farm turnout can be standardized using the PET of the particular crop mix grown in each year. This resulted in an indicator termed the net Relative Water Supply (RWS_n). RWS_n is seen in Table 5.4 to decrease over the past 30 years, with an average value of 1.46 for the period.²⁴ This means that, on average, the amount of water delivered to the farm turnouts was 1.46 times the weighted average crop water requirement.

As indicated earlier, to evaluate an indicator and make value judgements about its level, it is necessary to have a standard against which to compare it. What then are standards of acceptable water adequacy in the CBP? For the individual farmer, the avoidance of water stress would likely be a principal objective, suggesting that adequacy and timeliness of deliveries are paramount. Since districts are farmer-owned and operated, it is reasonable to assume that the district managers generally share this value, though they may have other values as well, such as maximizing power revenues or minimizing district operating costs. This suggests that districts would have implicit RWS_n standards similar to those of their farmer members. The value placed on meeting full crop PET requirements by Bureau personnel prior to the transition to self-management is uncertain, though by most accounts Bureau personnel were highly professional and dedicated to providing farmers with the irrigation service they requested.

²⁴ Note that this formulation does not include a leaching requirement. Under arid conditions, leaching of salts is necessary and important and would add something to the denominator of the RWS were it considered. Off-season rainfall would provide for some of this requirement. The leaching fraction would probably not vary substantially across the basin or over time, however, and so its absence does not compromise relative comparisons.

Table 5.4. Five-year average values for PET, net supply and RWS_n (in feet), CBP, 1955–89.

5-Year period	PET	Net supply	RWS_n			
	CBP	CBP	CBP	Quincy	East	South
1955–59	2.61	4.30	1.65	1.67	1.69	1.55
1960–64	2.81	4.15	1.48	1.53	1.46	1.42
1965–69	2.84	4.24	1.49	1.51	1.54	1.43
1970–74	2.89	4.23	1.46	1.53	1.48	1.36
1975–79	2.81	3.99	1.42	1.49	1.41	1.35
1980–84	2.70	3.61	1.34	1.36	1.35	1.31
1985–89	2.75	3.72	1.35	1.40	1.28	1.35
1955–89	2.77	4.03	1.46	1.50	1.46	1.40

Sources: PET computed from data in James, Erpenbeck, Bassett, and Middleton, *Irrigation requirements for Washington — estimates and methodology* (Pullman: Washington State University, 1989), pp 6–13. Net supply computed from data in U.S. Bureau of Reclamation Water Distribution Reports for CBP.

With respect to water adequacy, a farmer would require a RWS_n of at least 1.11 at his farm turnout to meet the full PET demand if his application system operated at an efficiency of 90 percent, or 1.25 if it operated at 80-percent efficiency.²⁵ An average RWS_n value of around 1.5 would imply that the adequacy objective is generally being met, assuming reasonably even distribution of water within each district.

While avoidance of crop water stress is a prime objective, farmers also want to minimize water and pumping costs. This generally means ordering and applying no more water than is necessary to meet crop PET. Farmers would therefore be expected to try to bring the amount of water delivered to their farms down as close as possible to the target RWS_n value dictated by the design parameters of their water application system. Final period (1985–89) RWS_n values of 1.35 are approaching the range of assumed target or standard levels, suggesting that deliveries to farms cannot be reduced too much further unless cropping patterns evolve further toward less water-intensive crops. This issue can also be addressed in the context of efficiency of water use, and is discussed from this perspective in a subsequent section.

Timeliness.

Timeliness would be best considered by comparing seasonal PET curves with records of water orders and then comparing the water orders with the timing of water deliveries in a two-stage process similar to the one described in the case of adequacy. However, reports from both farmers and district officials indicate that water orders have almost always been satisfied promptly both before and after transfer. Substantiating this perception is the result of a recent study of a large irrigation district in Arizona. Here Palmer, Clemmens, and Dedrick (1990) found that 72 percent of water orders were filled within 24 hours of the order date. It was, therefore, felt unlikely that the time-consuming analysis necessary to assess this dimension of performance, and assembly of

²⁵ It is possible that some farmers might try to operate below the peak of the production function curve if economic optimality was achieved by applying less than the full PET requirement to reduce operating costs. It is assumed that because costs of water and energy are relatively low in the CBP and the costs of miscalculation are high, this would not be an attractive strategy there.

the large volume of data it would require, would yield useful insight into the transfer process in the CBP. Consequently, it was deleted from the analysis.

Equity.

In the absence of information on distribution of water within districts, equity of distribution was assessed in a simple way by creating a series of ratios of the high and low RWS found among the three districts each year. Since this ratio is based on relative water supply, it has already been adjusted for the differing areas of the districts and their different cropping patterns. In a sense, it thus represents the ratio of the water supply made available to the best supplied and the worst supplied of the three districts, if they were to have identical areas and cropping patterns.

The equity index can be computed in two different forms, from the available data. The first uses the total diversions into each district main canal as the supply, together with the in-field demand represented by the weighted average PET. In the second formulation of the index, losses and wastage in the conveyance system are netted out, and the numerator is the aggregate delivery at the farm turnout while the denominator is the weighted average PET. The second index is examined here, since it is considered to be the most consistent with the operational objectives of both the districts and the Bureau, which are based on the meeting of irrigators' requests for water as measured at the farm turnout.

The average value of the equity index for the 1960 to 1989 period is 1.10, a remarkably low value by international standards (Table 5.5). Although this index says nothing about the distribution among farms within a district, it shows that, on average, the best watered district received only about 10 percent more water relative to its crop needs than did the district with the lowest RWS. East and Quincy Districts took turns as the "high" district, while South District was consistently the "low" RWS district.

The behavior of this equity index over time is shown in Figure 5.13. A rising index accompanying the expansion of the system in the 1960s indicates decreasing intradistrict distributional equity. Following management transfer in 1969, the index remained at peak levels for several years before beginning to move downward in 1975. After a ten-year period of decrease, indicating increasing equity, the ratio rose quickly again to the levels of the early 1970s. It is clear that management of water allocation and distribution by districts does not have a negative effect on interdistrict equity of water distribution. Districts appear to have managed and coordinated their operations in such a way that interdivisional equity increased steadily under their stewardship during the late 1970s and early 1980s. The reason for the rise in the index in the late 1980s is unknown, but may relate to physical deterioration within some districts and a consequent reduction in control over deliveries. It must be borne in mind that the differences in RWS which underlie the equity index are quite small and that even the highest equity index levels reached during the period are extremely low (indicating a high level of equity) compared to situations in most developing countries.

The interpretation of equity index values is somewhat different in an arranged-demand system, such as the CBP, than it is in a supply-driven system like those typically found in South and Southeast Asia. In the latter case, inter-unit equity is often established as an explicit operational goal and achievement of this goal can be considered as a direct measure of the effectiveness of the irrigation system. Additionally, the equity objective would often be framed in terms of water supply per unit area, rather than in terms of the supply relative to crop demand though this is not always the case. For the CBP, measures of equity can be computed *ex post*, but they do not serve, in any direct sense, as operational performance guides or indicators, since operational objectives relate to satisfying farmers' expressed requests for water, which presumably are related to the water requirements of the crops they are growing. It is interesting to note, though, that excellent equity

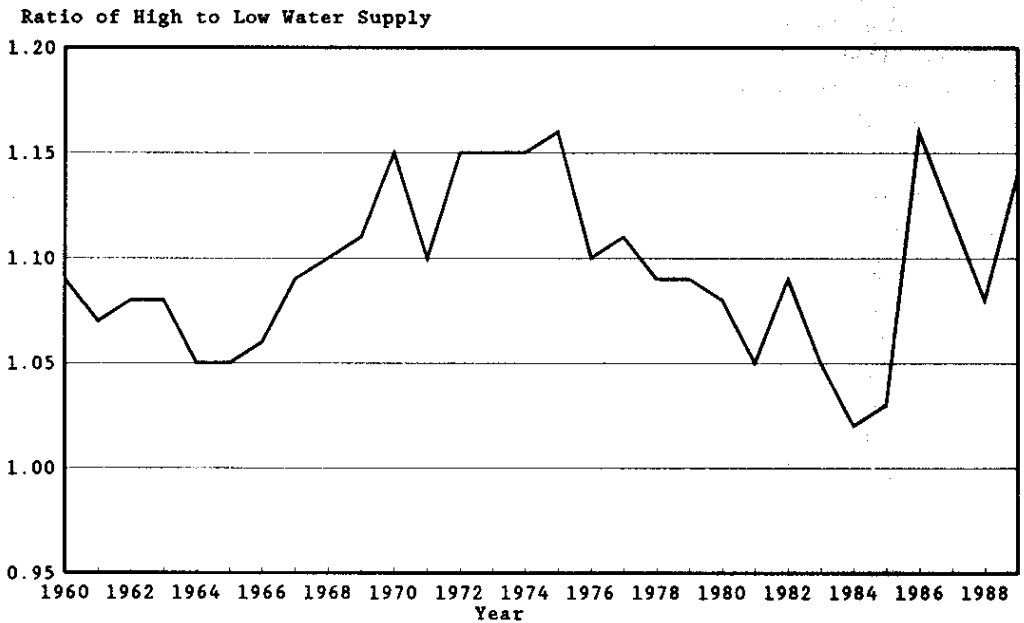
of distribution, at least at the district level, appears as a byproduct of a water allocation plan aimed at satisfying farmers' expressed demands. It must be remembered that variable costs of production in the CBP are related to the volume of water used, directly through water charges paid to the districts and indirectly through private pumping costs for operating sprinkler systems. This type of cost-linkage mechanism exerts downward pressure on water orders across the system, which can lead to high levels of intradistrict equity as crop-related water demand levels are approached.

Table 5.5. Ratio of high-district and low-district net relative water supply values for the CBP, 1960–1989.

Year	High district	Low district	Ratio
1960	Quincy	South	1.09
1961	Quincy	South	1.07
1962	Quincy	South	1.08
1963	Quincy	South	1.08
1964	Quincy	South	1.05
1965	Quincy & East	South	1.05
1966	East	South	1.06
1967	East	South	1.09
1968	East	South	1.10
1969	Quincy & East	South	1.11
1970	East	South	1.15
1971	Quincy	South	1.10
1972	Quincy	South	1.15
1973	Quincy	South	1.15
1974	Quincy	South	1.15
1975	Quincy	South	1.16
1976	Quincy	South	1.10
1977	Quincy	South	1.11
1978	Quincy	South	1.09
1979	Quincy	South	1.09
1980	East	South	1.08
1981	Quincy	South	1.05
1982	Quincy	South	1.09
1983	East	Quincy	1.05
1984	Quincy & South	East	1.02
1985	Quincy	South	1.03
1986	Quincy	East	1.16
1987	Quincy	East	1.12
1988	Quincy	East	1.08
1989	South	East	1.14
Period Averages			
1960–1968	(pre-transfer)	1.08	
1969–1989	(post-transfer)	1.10	
1960–1989	(total period)	1.10	

Source: Calculated from U.S. Bureau of Reclamation water distribution data.

Figure 5.13. District ratios of high and low net relative water supply, CBP, 1960–89.



Source: Computed from Water Distribution Reports for CBP, U.S. Bureau of Reclamation.

Hydrologic Efficiency

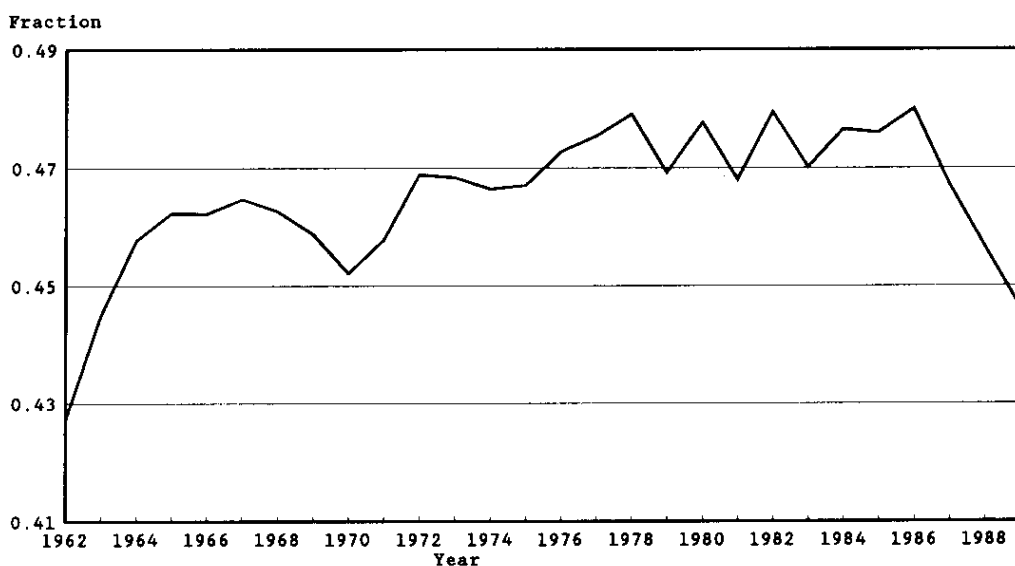
Efficiency is usually defined as a measure of the output of a process divided by the input used in the process. "Hydrologic efficiency" refers to the water delivered to a particular point in the system, or used in some way by agricultural operations and processes, divided by the water supplied from some upstream point. It does not measure the quality of irrigation service provided to irrigators, but reflects the amount of water lost in the process. Moreover, it is only a partial measure of irrigation efficiency, because it considers a single input (water) to a process which has many inputs (money, personnel, equipment). Nevertheless, hydrologic efficiency has often been taken as the key indicator of the performance of an irrigation system, and measures of hydrologic efficiency often yield very useful insights into system operating characteristics.

Tertiary unit efficiency, conveyance efficiency, and overall or project efficiency of the CBP are assessed following the terminology used by Bos and Nugteren (1990). In the absence of system deliveries for nonirrigation purposes, tertiary unit efficiency (e_u) can be defined as PET divided by aggregate water deliveries to farm turnouts; conveyance efficiency (e_c) as the quantity of water turned into system main canals divided by aggregate deliveries to farm turnouts; and overall efficiency (e_p) as PET divided by the quantity of water turned into system main canals (or $e_u e_c$). In general, e_u is a function of the type and condition of technology used on the farm and the quality of an individual farmer's management. The other efficiency, e_c , is a function of the management exercised by the irrigation district and the lining and water control technology it employs, as well

as its state of repair. Both efficiency measures are also dependent on soil characteristics, such as infiltration rates and evaporation rates, which are assumed to be constant from year to year.

Figure 5.14 shows the overall efficiency of the CBP over a 27-year period as a series of three-year moving averages. Efficiency is defined as system-wide PET divided by net supply at the bifurcation. This means that the effects of return flow reuse in South District are already included in the efficiency calculation.²⁶ It is seen that maximum efficiency levels are achieved in 1978, 1982, and 1986, well after the transfer to district management. Beyond that simple observation, however, the figure suggests several distinct periods that bear further scrutiny. These are: (a) the rising portion from 1962 until 1968; (b) two sharply falling years, 1969 and 1970; (c) a period of rising efficiencies from 1971 until 1978; (d) generally high but variable values from 1979 to 1986; and (e) a sharp decline in overall efficiency from 1987 to 1989.

Figure 5.14. Overall efficiency of CBP, 1960–89 (3-year moving average).



Sources: Water Distribution and Crop Production Reports for CBP, U.S. Bureau of Reclamation. PET calculated from data in James, Erpenbeck, Bassett, and Middleton, *Irrigation requirements for Washington — estimates and methodology* (Pullman: Washington State University, 1989), pp 6–13.

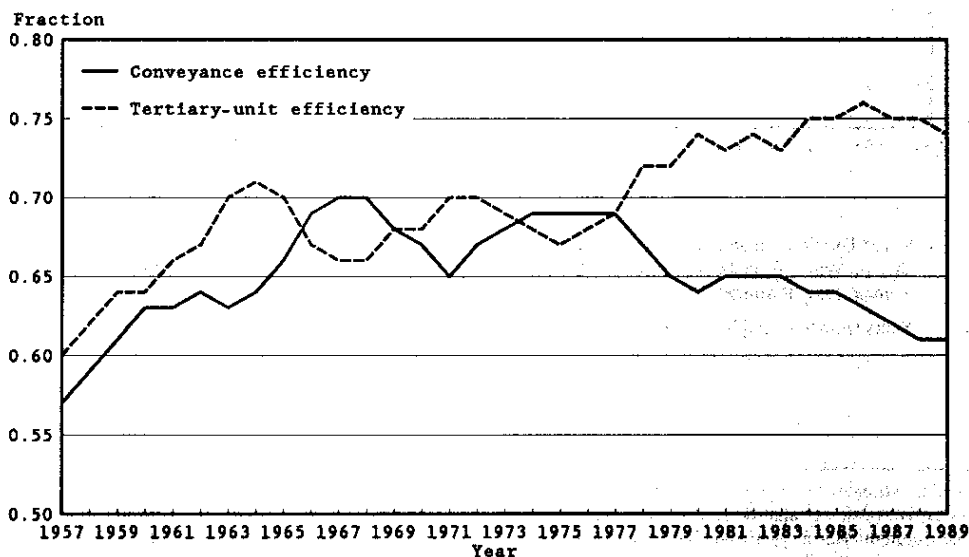
Note: Years shown on graph scale are final years in each 3-year period.

²⁶ Keller estimates the overall efficiency of irrigation water use along the lower Nile to be about 70 percent, when the extensive reuse of canal-derived surface drainage flows and groundwater is considered. Ignored in this discussion of the Columbia Basin system are the extraction and use of CBP-derived water by groundwater districts within the overall project boundary. The source of this groundwater is recognized by both parties and compensatory payments are made by groundwater districts to CBP irrigation districts, but the volume of such reuse is not known and is not considered in the efficiency calculations. On the other hand, natural rainfall-derived inflows to the Potholes Reservoir are also not included in the calculations and would offset, to some extent, the gains in overall efficiency which would result from a consideration of groundwater reuse. The point is that boundary definition and consideration of reuse can generate large differences among alternative determinations of project "efficiencies."

When it is recalled that most of the CBP was turned over to the irrigation districts to operate in January 1969, the following interpretation emerges. The early sixties were a period of rapid system expansion and learning for both farmers and Bureau managers, resulting in steadily improving overall efficiency. When transfer took place in early 1969, efficiency of operation suffered, both because districts were new to canal management, and perhaps because less predictable or reliable deliveries also affected farmers' ability to manage tertiary-level distribution and application efficiently. A learning process quickly set in again, however, coupled with physical improvements mandated by the transfer agreements and improved application technology at the farm level, resulting in generally improving efficiencies for the next 16 years. There is no obvious explanation for the sharp decline which set in 1987. Possible reasons include: an underfunding of system maintenance by the districts, which was implied in some interviews with district managers; a general age-dependent system deterioration which could not be offset even by generally adequate maintenance expenditures; and changes in system operating rules, perhaps to accommodate newly installed hydropower generating capacity within the command.

To explore this interesting scenario further, overall efficiency was disaggregated, and the two component efficiencies are shown in Figure 5.15 as three-year moving averages. The figure shows that conveyance efficiency increased steadily from 1957 until 1968, rising by about 13 percentage points. In 1969, it fell sharply and is clearly responsible for the precipitous fall in overall efficiency in the same year. This behavior supports the hypothesis that the decline in overall efficiency is related to the transfer, because such a decline would be expected to show up most directly as reduced conveyance efficiency. After three years of decline, during which it dropped 5 points from 0.70 to 0.65, conveyance efficiency again increased for several years climbing back to about 0.69. During this period, it was once again responsible for a net rise in overall efficiency. From 1975, conveyance efficiency for the CBP declined continuously until the end of the period in 1989, ending at about 0.60.²⁷

Figure 5.15. Conveyance and tertiary-unit efficiency, CBP, 1955-89 (3-year moving average).



Source: Water Distribution and Crop Production Reports for CBP, U.S. Bureau of Reclamation.

Note: Years shown on graph scale are final years in each 3-year period.

²⁷ Bos and Nugteren (1990, 33) present data showing average conveyance efficiencies of about 0.53 for schemes larger than 100,000 hectares. The sample is drawn from nonrice growing irrigation systems in a mixture of developed and developing countries.

Tertiary-unit efficiency, on the other hand, also rose smartly from 1957 and then fell before beginning a four-year rise in 1969, the year of the transfer, from 0.65 to about 0.70.²⁸ From 1975, six years into the district management period, until 1986, steadily rising tertiary-level efficiency offset falling conveyance efficiency, holding overall efficiency generally constant. As tertiary efficiency levels off, however, and conveyance efficiency continues to fall, overall efficiency drops sharply for the last 3 years of the period resulting in the 3-percentage-point decline in overall efficiency recorded between 1987 and 1989.

The evidence presented above suggests a post-transfer acclimation period lasting about 7 years before system conveyance efficiency was restored to levels prevailing prior to transfer. This was the case with a staff largely made up of the same individuals who had operated the scheme before 1969. If it had been necessary to recruit and train O&M personnel from outside the system, this period could conceivably have been longer. It should be noted that there is no evidence that the adequacy or timeliness of water deliveries to farmers suffered during this period, or that interdistrict equity deteriorated. It is only the hydrologic efficiency of the canal system operations which was obviously affected.

The long, steady slide in conveyance efficiency which has lasted from 1975 until the present raises additional questions. First, is this a matter of concern to system managers? If quality of irrigation service to CBP farmers has not suffered, and this is the direct connection with the productivity of the system, it may be that reduced conveyance efficiency is a step consciously taken to make system management easier and to reduce field staffing requirements, and hence operating costs. Alternatively it may be that the conveyance system is simply leakier and less manageable than it was in the mid-1970s, as a result of inadequate maintenance and replacement work on system canals, linings, and control structures. A third possibility is that system operational rules and procedures have not been appropriately adapted to the decline in aggregate crop water demand which has occurred since the early 1970's and the corresponding decline in the aggregate volume of water orders, adjusted to a per-acre basis. In this case, more water in main-canal systems is simply running to waste. These questions will be explored further as additional information is presented to illuminate them from different angles.

Financial Viability

Adjusting for Inflation.

In the following financial analyses, three price indices are used to remove nominal increases attributable to inflation from project and farm-level costs and returns. All values reported in the analysis of revenues and costs are in constant 1989 US dollars unless otherwise indicated.

Value of crop output was adjusted to constant dollars using the index of prices received by farmers, and the farm-level price of water was adjusted by the index of prices paid by farmers, both taken from the Economic Report of the President (1991). Operation and maintenance (O&M) costs, as well as other CBP revenues and expenditures were adjusted using the Producer Price Index (PPI) from the same report. The PPI is a generalized index of prices paid by producers of goods and services for inputs, calculated for the entire United States.

The USBR maintains its own deflator series for O&M expenditures, based on changes in per-acre O&M expenses in a sample of its own projects. The USBR sample excludes projects whose total area varied by more than 20 percent from the previous year and whose O&M costs

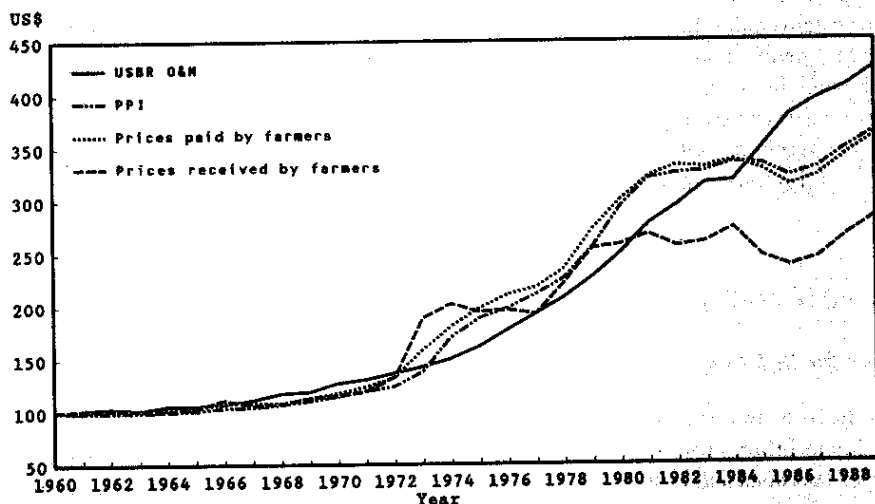
²⁸ Bos and Nugteren (1990, 55) report an average e_u value of 0.70 for six sprinkler-based systems. The sample is drawn from irrigation systems in a mixture of developed and developing countries.

varied more than 50 percent from the previous year. Sample projects are allowed to have only minimal changes in management, system physical condition, or maintenance standards for that year. An index is first calculated for each project and the individual indices are averaged to obtain a general index. The cost streams upon which the USBR index is based are specific to USBR projects and include any real changes in O&M expenditures as well as inflation-induced changes.

The four series are shown together in Figure 5.16. Comparison of them reveals several interesting trends. First, the index reflecting prices paid by farmers tracks the PPI closely, making the two interchangeable for practical purposes. Second, both of these measures leveled off in 1982, reflecting the onset of a recessionary period in the United States, and remained stagnant for the next 5 years.

During the same period, the USBR O&M index appears unaffected by medium-term trends in the larger economy. Its resolute rise during both inflationary and noninflationary times suggests that either the cost structure of the Bureau is pre-programmed for a particular level of inflation and therefore unresponsive to real outside events, or that, because of the way the index is constructed, it is being driven upward by real-cost increases in O&M expenditure in addition to inflationary ones. Consequently, the Bureau index was felt to be insufficiently independent of sampling biases and the impacts of real changes in system O&M costs to be used in deflating CBP O&M expenditures.²⁹

Figure 5.16. Comparative deflators for irrigation cost series, 1960–89 (1960=100).



Sources: President of the United States, *Economic Report of the President* (Washington, D.C.: U.S. Government Printing Office, 1991); O&M Cost Index calculated by U.S. Bureau of Reclamation.

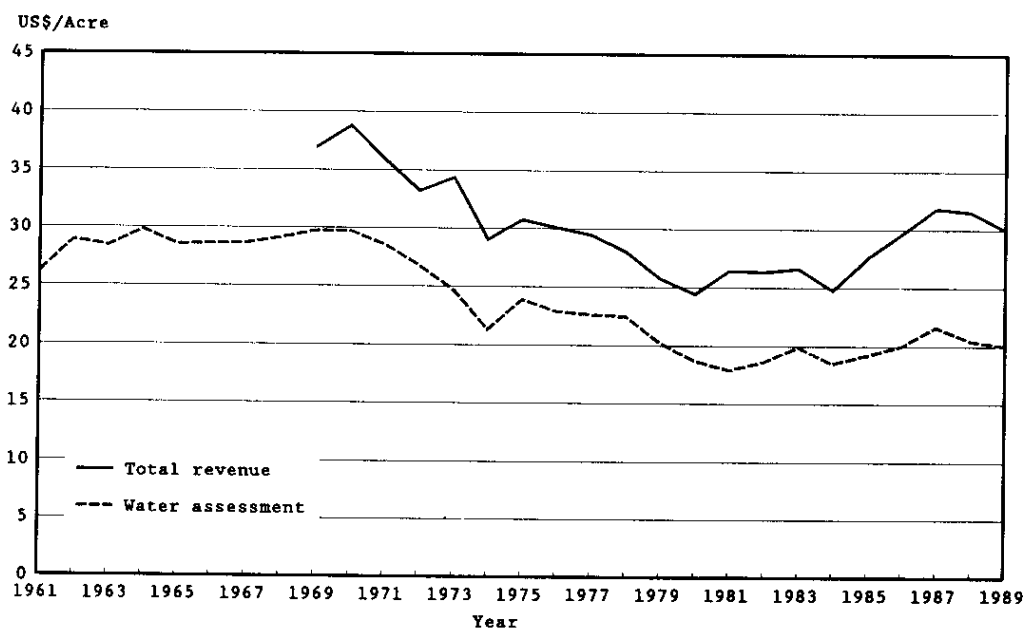
Revenue

Total revenues to the three districts averaged US\$37.15 per acre, in constant 1989 dollars, for the three-year period 1969–1971 immediately following the districts' takeover of operational

²⁹ Note also that prices received by farmers leveled off in 1980 while other indices continued to rise steadily, highlighting the cost/price squeeze in which farmers were caught for almost a decade.

responsibility. Revenues fell steadily over the next decade, reaching a low of US\$25.53 per acre for the 1979–1981 period. Income then rose again during the eighties, reaching US\$31.09 per acre in 1987–1989 (Figure 5.17).

Figure 5.17. Revenue per irrigated acre, CBP, 1961–89 (1989=100).



Sources: U.S. Bureau of Reclamation and CBP irrigation districts.

Driving these changes were variations in income from water assessments charged to Basin farmers, which make up 70 to 80 percent of total revenue. As seen in Figure 5.17, total revenue closely tracks the water assessment curve during the 1969 to 1989 period, with some divergence toward the end of the period. Data on water assessments are available from 1961 and provide an opportunity to compare trends in assessments before and after management transfer. From a level of US\$26.16 per acre in 1961, the assessment rose rapidly to US\$29.10 in 1968, the final year of Bureau management. Following management transfer to districts, assessments fell steadily, reaching a low of US\$17.91 in 1981 before beginning to rise slowly again reaching US\$20.00 per acre in 1989. It seems clear that the management shift triggered a series of reductions in real water assessment rates and reversed the rising trend which had been prevailing prior to that time. Farmers, through their districts, appear to place a higher premium on holding down fee assessments than does the Bureau. The increasing trend of the early 1980s may represent a realization that maintenance was being underfunded, but this point requires further exploration. Another interesting feature of Figure 5.17 is the expanding divergence between total revenue and water assessment curves after 1984, suggesting the increased importance of other sources of income to the districts after that time.

Table 5.6 shows shares of total revenue derived from different sources. Farm water assessments, the major component, declined from 80.6 percent in 1969 to an average of 67.4 percent during the last half of the 1980s. On the other hand, power revenues became appreciable only in 1985, and, in the last half of the decade, made up 4.5 percent of total revenue. The category "interest and other revenue" also shows an increase during the last 5-year period, rising to 14.8 percent of the total.³⁰ Income from water-service contracts grew steadily throughout the 20-year period of district management, representing system expansion into adjacent lands not formally included in the district. The growth in these other income sources caused the total income to the districts to climb rapidly from 1984 onward, while allowing districts to restrict water assessment increases to relatively modest levels. Total real income grew at a compound rate of 4.1 percent during the 1984 to 1989 period, while water assessments increased only at a rate of 1.9 percent per year.

Table 5.6. Shares of total revenue, 5-year averages, CBP 1969-89.

Year	Water assessment	Water service contracts	Excess water charges	Interest and other income	Power revenue	Total
1969	0.806	0.003	0.122	0.070	0.000	1.000
1970-74	0.764	0.014	0.126	0.095	0.000	1.000
1975-79	0.778	0.033	0.116	0.075	0.000	1.000
1980-84	0.729	0.042	0.060	0.166	0.004	1.000
1985-89	0.674	0.057	0.076	0.148	0.045	1.000

Source: Data from CBP irrigation districts.

Three salient conclusions emerge from this analysis. First, districts were effective in substantially reducing the absolute level of irrigation rates after they assumed management control. That they would wish to do this is not surprising, though their effectiveness is notable. Second, all three districts have succeeded in diversifying their activities to generate a larger share of their revenue from sources other than their member farmers. Each district now gets more than one quarter of its total revenue from non-member sources. In addition to new sources of income such as small-scale hydropower generation, districts have reduced their own water use, and hence revenue from excess water sales, and sold this water to other farmers on the margins of the districts, boosting revenue from water service contracts. Third, interest earnings has become an increasingly important source of income for the districts, suggesting prudent financial management and the accumulation of sinking and other reserve accounts.

Costs

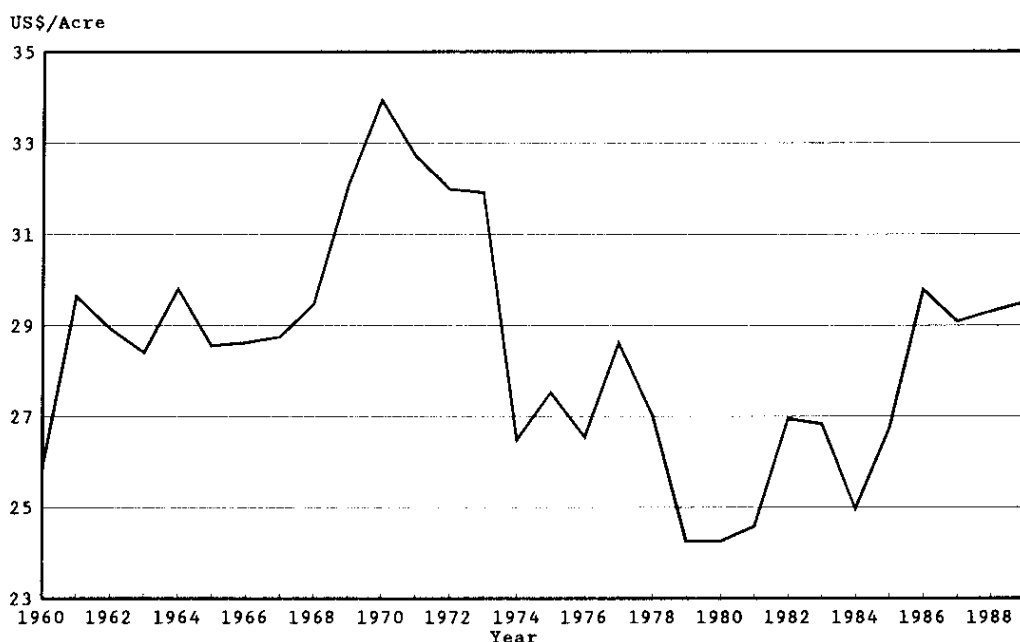
The cost of operating the CBP during the period 1960 to 1989 averaged US\$28.43 per acre (US\$70.22 per hectare). Counted are financial (not economic) costs which include district

³⁰ For the period 1983 to 1989 for which disaggregated data are available, more than half (53.8%) of the income in this category consists of interest income on funds held on account, and reserve funds. The balance of the income shown comes from groundwater recharge payment from groundwater districts and transfers from reserve funds (16.7%), payments by the USBR for services provided by the districts (11.7%), miscellaneous collections (9.5%), and equipment rental (6.3%). These figures are averages over seven years. Proportions for individual years fluctuate substantially.

operating expenses and the district payment to the Bureau for operating and maintaining reserve works, but not subsidies provided through the Bureau. Most notable among the latter is the exceptionally low rate paid by the districts for lifting water from the FDR Reservoir, relative to commercial rates for power.

Figure 5.18 shows the behavior of operating costs over time. Immediately following the shift from Bureau to district management, costs are seen to have increased substantially. During the period prior to the transfer (1960 to 1968) the average operating cost was US\$28.67 per acre, while during the five-year period following transfer (1969 to 1973) it averaged US\$32.51 per acre, an increase of about 13 percent. In 1974, it plunged decisively and remained relatively low for the next 8 years before showing a rising trend throughout the 1980s. For the entire post-transition period (1974 to 1989), the average operating cost was US\$27.02 per acre, only slightly below its value under Bureau management. It is reasonable to regard the increase in operating costs immediately following transfer as temporary and to attribute it to the transition process itself. Although the Bureau covered many of the costs involved, the districts must have incurred start-up costs of establishing or expanding offices, setting up databases and accounting systems, and the like.

Figure 5.18. Total expenditures per acre, CBP, 1960–89.



Sources: U.S. Bureau of Reclamation and CBP Irrigation Districts.

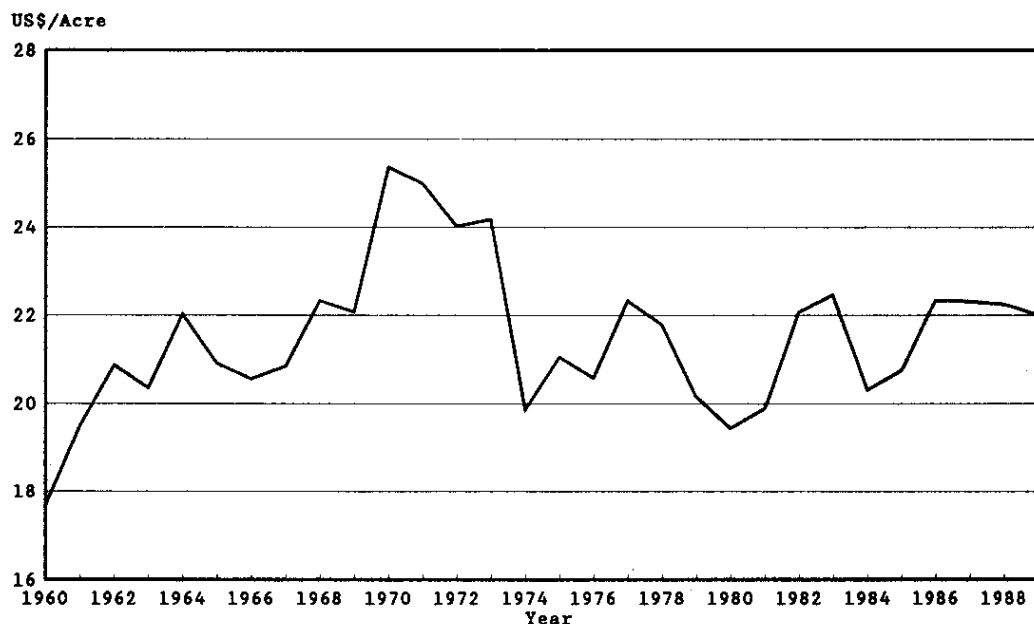
In general, about three quarters of total operating costs (76 %) are made up of district staff and O&M expenses (Staff/O&M).³¹ Payments to the Bureau for "reserve works" O&M make up another 13 percent, and "other" costs amount to 10 percent of the total. The Staff/O&M category

³¹ Given the various sources of the data used in this analysis, it was impossible to disaggregate this category in a consistent way.

includes staff salaries and benefits, and such items as maintenance on buildings and canals, lateral construction and repair, weed control, staff field expenses and equipment expenses. "Reserve works" includes payments to USBR for operation, maintenance and repair of canals, dams, and pumping plants used in common by the three districts and power charges for pumping from the FDR Reservoir. The "other" category includes contracted construction work, insurance claims, drainage claims, unrecovered assessments and charges, and administrative expenses.

Figure 5.19 shows Staff/O&M costs to be remarkably constant over time, if the transition period is ignored, with costs before and after transfer being quite similar. This is consistent with the earlier observations that operational procedures changed little after transfer and that most of the operational staff simply switched employers. Although year-to-year variations in Staff/O&M costs can be seen reflected in the total expense graph, the reduced *level* of total expenditures during the late 1970s is explained by the steady reduction in reserved works expenditures shown in Figure 5.20. With the exception of the transition period, these expenditures show a long-term decline over 25 years from about US\$5.50 per acre in 1960 to around US\$2.00 per acre in 1984. Subsequently, there was a near doubling of the expenditure rate during the late 1980s. The fall in this category of expenses is a result, in part, of falling per-acre water supply levels and consequent reduced power charges. This trend is mirrored, in more muted fashion, by "other" expenditures (Figure 5.21).

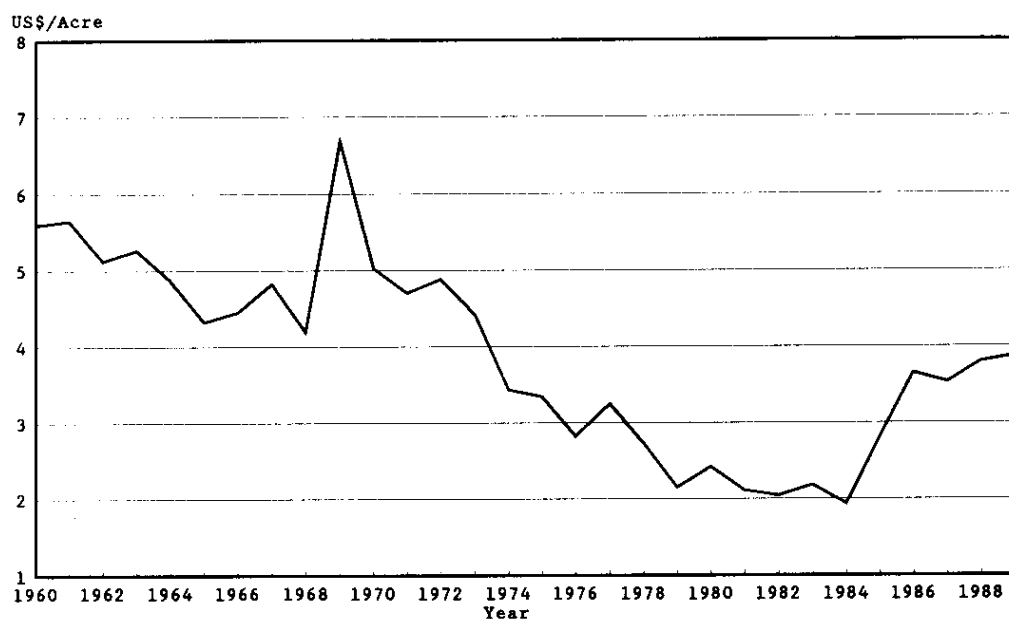
Figure 5.19. Per-acre expenditure on staff and O&M, CBP, 1960-89.



Sources: U.S. Bureau of Reclamation and CBP irrigation districts.

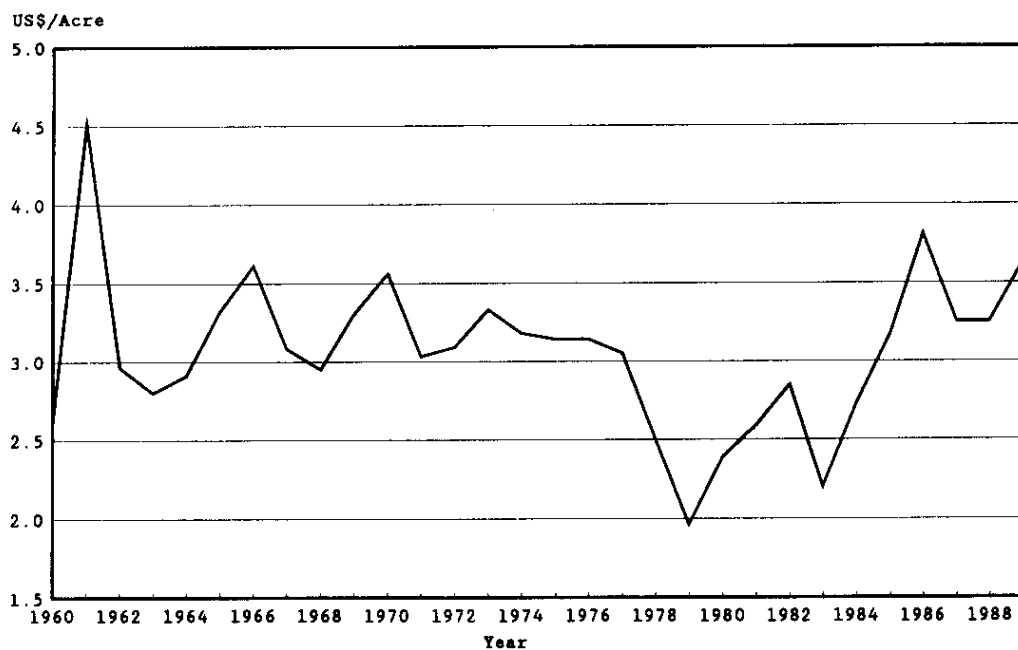
The general pattern which emerges is of relatively little permanent change in expenditure patterns as a result of the transfer of management to the districts. Staff/O&M and "reserve works" expenditures both experienced temporary, transition period increases following transfer, following which staff/O&M costs settled back to their previous range while "reserve works" assessments continued to fall until the mid-1980s. Total O&M expenditures also show this transition spike and

Figure 5.20. Per-acre expenditures on reserved works, CBP, 1960-89.



Sources: U.S. Bureau of Reclamation and CBP irrigation districts.

Figure 5.21. Other expenditures per acre, CBP, 1960-89.



Sources: U.S. Bureau of Reclamation and CBP irrigation districts.

subsequent fall to values below pre-transfer levels. During the last half of the 1980s, rising reserve works assessments and increasing administrative and other costs pushed total expenditures back to the level prevailing prior to transfer.

An interview with the Quincy district manager indicated that farmers' top priority is a "lean" operation to keep water charges down. Reportedly, the board restricts costs tightly and the district is "right on the line" between maintaining the system in adequate operating condition and letting it deteriorate. Others interviewed in that district felt the system is being allowed to deteriorate. For the system as a whole, the figures examined do not reveal an overall decline in the amount spent in the critical Staff/O&M category, a decline which might suggest that short-term economies are being sought at the expense of long-term sustainability. However, as system facilities and equipment age, it may be that the expenditures *required* to hold the system at a particular level of operational performance increase. Hence, constant real levels of expenditure would become increasingly inadequate.

Profitability

Time series data on farm expenditures and production were not available to allow the calculation of annual farm profitability. From a farmer's perspective, profitability is the ultimate measure of the performance of his operation, but it is a measure obviously influenced by a large number of variables besides the quality and cost of irrigation service. The major effect on profitability of the shift to farmer management of the CBP was probably felt through the one-third reduction in per-acre irrigation assessments which took place following the transfer. For a 160-acre farm, this would amount to an increase in gross margin of around US\$1,600. The more precise water control provided by center pivot sprinklers, which facilitated a shift to higher-value crops, probably had a much greater impact on profitability, but this change was a farm-level decision and largely independent of the management transfer.

Several existing studies carried out with somewhat different purposes in mind do provide interesting snapshots of profitability in different years. A study by the Washington State Department of Conservation in 1964 compared net annual returns per acre on sample farms on the unirrigated wheatland on the East Side (where farmers had refused irrigation when the project was being developed) with returns in the irrigated area of the CBP. Average net annual returns on the unirrigated land were US\$6.54, compared with a range of US\$17.60 to US\$41.33 per acre on the irrigated farms. Unsurprisingly, irrigated land has been substantially more profitable per acre than adjacent unirrigated land. East side farmers objected to the introduction of irrigation due to their collective opposition to the accompanying farm-size limitations. Because these farmers did retain larger holdings, however, these per-acre figures do not reflect respective farm income levels for the two groups.

A 1978 study (Holland and Young) concluded that farm units of 160 acres were economically viable and profitable. Using average prices and crop yields for the period 1973 to 1977, the profit maximizing wheat-potato rotation yielded a net annual after-tax income of US\$29,000. The less-intensive but more common rotation of sugar beets, wheat, alfalfa, and potatoes, which was considered more consistent with maintaining soil fertility, yielded a much lower average net annual income of US\$10,000. Both levels were considered "adequate" to support an average family of two parents and two children. Put into 1989 dollars, these net incomes work out to US\$31,958 and US\$11,020 respectively. If the 1964 figures for irrigated farms from the Department of Conservation study are put on a similar footing, net income in that year spanned a range of

US\$4,618 to US\$10,845, or an average of US\$7,732. This suggests that net farm incomes did rise, in real terms, between 1964 and 1978.

A final illustrative comparison relates a farmer's water cost savings due to the post-transfer drop in assessment levels to net farm income. From Figure 5.17, the change in per-acre assessment levels between the 1960s and the 1980s is seen to be about US\$10 (1989 dollars). This amounts to US\$1,600 for a 160-acre farm. Assuming that the real after-tax farm family income in the 1980s remained at the 1978 level, savings in water charges are seen to have comprised about 15 percent of the farm family's income. In other words, average farm income would have been roughly 15 percent lower had management transfer not occurred. This calculation is crude, but it does suggest the order of magnitude of the savings involved, which is substantial.

As indicated earlier, the gross returns from CBP farms have increased steadily, in real terms, since the project was constructed (Figure 5.5). Because the behavior of production costs is unknown, however, the authors are unable to make judgements on this basis about net income.

Maintenance

Under the terms of the management transfer agreement, the USBR is to conduct an O&M audit of system network facilities and operations in each of the districts every two years. Such audits generally involve three days of field inspections by a team of USBR and consulting engineers.

Table 5.7 shows the results of six O&M audits conducted after management transfer, between 1973 and 1988. Audits of pumping stations were conducted during alternate years. There were 37 recommendations made during the six audits in the three districts, an average of 2.05 recommendations per audit per district. Remedial action in response to 13 of these recommendations was not completed prior to a subsequent audit. This yields an average of 0.72 uncompleted recommendations per audit per district.

Recommendations are divided into three categories by the auditors. Category 1 recommendations are those where urgent remedial maintenance is required. There were no recommendations made in this category. Category 2 recommendations call for important, preventive maintenance work. This was the most common type of recommendation made to the districts, constituting 30 of the 37 recommendations. Category 3 recommendations are for less important, preventive maintenance work. Seven of the 37 recommendations were in this category.

The recommendations covered a variety of types of work. Some of the more frequently made recommendations called for repair of structures and mechanical devices, painting, better on-farm irrigation management — especially to prevent silt-laden farm run-off,³² weed control, canal seepage control, and improving drainage capacity. Operational practices were rarely commented upon. All three districts were commended for the quality of their overall O&M practices. The 1986 audit report for East District noted that all facilities reviewed were in "good operating condition" and that the district was continuing to "look for new ways to improve the operation" of the system. The 1990 audit report for Quincy District commended district staff for their "progressive O&M program" and noted that all structures observed were in good condition.

The overall view of operation and maintenance activities carried out by districts provided by the audits is positive. The number of recommendations is relatively small, given the total number of structures and length of canals across the three districts. The districts were engaged in a program of preventive maintenance which successfully kept the system from requiring emergency remedial maintenance.

³² This recommendation was more common in the earlier audits.

Table 5.7. Results of USBR O&M audits in three districts of the CBP.

	Previous recommendations uncompleted	Number of recommendations			
		New recommendations			Total
		Category 1	Category 2	Category 3	
1973	2	0	0	0	0
1975	0	0	5	1	6
1977	3	0	0	1	1
1979-81 ^a	4	0	12	2	14
1982-84	1	0	8	2	10
1986-88	3	0	5	1	6
Total	13	0	30	7	37

Sources: O&M audits, USBR, Columbia Basin Project.

Note: Category 1: Urgent remedial maintenance required; Category 2: Important preventive maintenance needed; Category 3: Less important, preventive maintenance would help improve O&M.

^aIn later years, audits were not conducted in each district during the same year.

The question of the drop in conveyance efficiency beginning in 1975 remains, however. Attributing such a change to particular causative factors is difficult as several factors are likely to be involved, because the effects of neglect are cumulative, and because time lags exist between neglect and deterioration. The level of Staff/O&M funding is a logical proxy for maintenance adequacy, but as seen in the analysis of costs, it has shown no persistent downward trend and small year-to-year variations would not be expected to show up as fluctuations in hydraulic efficiency. The possibility of increasing O&M requirements with time remains, however.

The O&M audits shown in Table 5.7 offer a proximate variable between inadequate maintenance and conveyance efficiency. These audits do show a higher level of new and uncompleted recommendations in the period after 1979, most of which were classed as "important preventative maintenance needed" which is roughly consistent with the timing of the decline in conveyance efficiency shown in Figure 5.15. This offers some limited support to the idea that O&M expenditures ought to be increasing if efficiency declines are to be arrested.

CONCLUSIONS

From many angles, the transfer of management from the US Bureau of Reclamation to irrigation districts in the Columbia Basin Project can be considered a success on a large scale. While the Bureau was able to back out of its mostly unwanted role in O&M, the districts gained local control over management and costs. Data suggests that the project has not suffered significant negative impacts due to management transfer in the areas of management efficiency, agricultural productivity, profitability of agriculture for farmers, or economic viability of districts. The effect on long-term sustainability of the system is less clear, and there is some indication that the physical system may be experiencing some net deterioration. That management of irrigation for approximately 557,528 acres (225,626 hectares) can be handled by three local irrigators' organizations is an impressive achievement. It is a recurring pattern throughout the American West,

even on larger scales. The King's River Irrigators Association in Fresno, California irrigates more than 450,000 hectares of land.

The aspects of the CBP which accounted for its ability to transfer such a sophisticated and large-scale management regime to local irrigators' organizations may be summarized as given below.

Social Context

In contrast to the situation in many developing countries, the CBP consisted of a relatively homogeneous population of settlers, which was highly educated and commercially oriented. There were virtually no landless poor or others with insecure tenure. Farmers and their districts had considerable legal and political power and secure land and water rights. Farmers were able to negotiate as equals with the government and obtain numerous favorable concessions for themselves, such as low power and construction repayment rates and relaxed limits on farm sizes. Such concessions ensured that farming would be a relatively stable and profitable enterprise.

From the outset of construction, irrigation districts were invited to negotiate and agree on whether or not they wanted the irrigation system to be constructed. The offer could be rejected and was by some. To obtain water, farmers established districts and entered into agreements with the government to repay construction costs, cover the "full" cost of O&M (which was in fact highly subsidized), and eventually take over management of the system. This initial collective understanding about responsibilities of individual farmers and the districts created the perception among farmers that management transfer was both desirable and inevitable. The essential practices of continual negotiating and making binding agreements no doubt strengthened the districts and their legitimacy in the eyes of the farmers.

Institutional Context

The system of contract law and the strong legal basis of the districts and their land and water rights provided the necessary confidence for farmers to accept responsibility for managing the system. Strong institutions also made possible the credible threat of strong sanctions. The "partnership culture" between the districts and the Bureau permitted joint problem-solving, as in deciding on continued Bureau management of jointly used "reserved works," contracting by the districts for technical work to be performed by Bureau staff, and the creation of satisfactory Bureau-to-district personnel transfer arrangements. The Bureau also provides sovereign immunity for the districts, acts as repository for the system's water rights, and has ultimate oversight responsibility for ensuring that standards of O&M and financial performance are maintained. The state ensures that standard accounting procedures and practices are followed.

No doubt management transfer would have been much more difficult to achieve had the Bureau and districts not been able to come up with an acceptable plan for rapid staff disposition. The districts were able to absorb the large majority of displaced O&M staff. They were already paying Bureau O&M staff costs prior to transfer, so transfer did not introduce additional major costs to the farmers. Bureau staff did not seriously resist the move, because transferred staff received the same salary levels and insurance and pension benefits as they did before transfer. The Bureau was able to reassign remaining staff elsewhere and also began to take on new roles to use its staff, which included land and environmental management and monitoring.

Results

Technology Adoption.

There has been substantial technological change in the CBP since transfer of management in 1969. Some of this change, such as the widespread shift to center pivot systems, has resulted from the individual decisions of farmers responding to prices and returns. Other changes, such as installation of automatic gauging stations and telemetry systems, have been put into place by the districts. It seems clear, at a minimum, that the transfer to district management has not hindered the adoption of new technology in the CBP and may have accelerated it.

Causes of technological change are sometimes complex and indirect. For example, the reduction in water demand which accompanied the rapid shift to sprinkler irrigation in the 1970s was shown to be largely a result of a shift to crops with lower water demand, rather than to the adoption of sprinkler systems *per se*. However, it is quite likely that the installation of the center pivots contributed to improved water control which made the shift to new, less water-intensive, often higher-value crops possible. And the willingness of farmers to invest in expensive new water application technology is itself, in part, a function of their confidence in the reliability of water supplies delivered by the district.

Hydrologic Performance

The quality of irrigation service received by CBP farmers does not appear to have been affected significantly by the change to district management. Quantity of water delivered did not change markedly after 1969 and reductions in water supply in later years can be explained largely by reductions in aggregate water demand resulting from changing cropping patterns. Demand adjusted equity of water distribution among the three districts did decline in the 1970s and the 1980s following transfer, but then rose again and, on average, equity at the district level was about the same before and after transfer. The CBP operates on an arranged demand system of allocation, and so timeliness of water deliveries must be measured against the timing of orders for water. Farmers appear to have been satisfied with the timeliness of deliveries both before and after transfer and generally rate this aspect of service highly.

An examination of the hydrologic efficiency of the system does reveal some interesting changes, however. It appears that the system's new managers required a period of 5 or 6 years after transfer before they were able to operate the conveyance system as efficiently as did the Bureau prior to transfer. This demonstrates the complex and subtle nature of the control that is required to operate a large system like the CBP efficiently. Farmers, for their part, increased tertiary-level efficiency steadily from the mid-1970s. Improvement was driven by a shift from surface to sprinkler irrigation across much of the project area. That rise has now stopped and overall tertiary-level efficiency may even be declining slightly at present.

One very puzzling aspect of system hydrology is the continuing 15-year decline in conveyance efficiency which set in 1978, accentuated by a strong upward surge in the amount of water turned into the three districts beginning in 1986. This recent increase is not reflected either in supplies actually delivered to farm turnouts or to any change in crop-based demand for water, both of which have held constant. Possible explanations for this overall deterioration in system conveyance efficiency include, (a) deterioration in the condition of major system canals resulting in increased water conveyance losses, and (b) increased water orders to the Bureau to allow greater power generation through turbines installed in a number of system canals.

In considering the second scenario, it is noted that the efficiency decline commenced well before power generation by districts began in 1985 and is clearly not responsible for the longer-term

trend. However, power to pump water into their distribution systems costs the districts less than one twentieth of what they earn from the commercial sale of the power they generate, on a per-unit basis. It would thus be quite rational for them to increase their water orders from the Bureau in order to increase revenues from the sale of power, simultaneously holding down the water rates assessed to district members. This would explain the sharp increase in deliveries to the districts beyond 1986. Such a move might have the added benefit of making the system easier to manage, especially toward the tail, by keeping more water flowing through it.

Financial Performance.

Upon assuming management responsibility, districts moved quickly to cut water assessments to district members. On average, real per-acre assessments under district management were just 78 percent of their level during the Bureau period. At the same time, districts diversified income sources, increasing the share of revenue from hydropower generation and interest on deposited funds, partially offsetting lost water assessment income. Sale of water conserved to non-members of the district also increased sharply, demonstrating the power of vested water rights, financial autonomy, and quasi-volumetric pricing to shift water to more profitable uses within the irrigation sector.

On the average, costs of operating the system do not exhibit well-defined shifts associated with management transfer, and average expenditure levels before and after 1969 are roughly similar. Although it is impossible to know what expenditure patterns would have been had the Bureau retained operating responsibility, the Bureau's agency-wide O&M cost index provides one clue. It shows that the cost of operating Bureau systems increases in an extremely regular way, in nominal terms, and is only loosely related to the underlying rate of inflation. Overall, since 1960, the Bureau's cost index has grown to a somewhat higher level than more general cost indices, suggesting that operating expenses under Bureau management might have been higher than they presently are, other things being equal.

Three quarters of operating expenses are made up of staff and O&M costs, and these have held remarkably constant across the transition. Major expenditure components show peaks just after transition, reflecting the one-time costs of the transfer. A ten-year decline in total expenditure from the 1969 peak is largely attributable to falling reserve works costs. During the last decade, total costs have risen again to around their long-term average, driven by increases in reserve works expenditures and administrative and other costs.

The cost analysis does shed a little more light on the question of declining hydrologic efficiency raised earlier. Because district O&M costs have not shown a declining trend since transfer, it can be assumed that maintenance levels at the district level have not been reduced appreciably. Changes in reserved works payments to the Bureau do not enter the argument, since the observed decline in conveyance efficiency occurred within areas of responsibility of the districts. A remaining possibility is that, while district expenditures on O&M have held constant, they should in fact be increasing to counter accelerating deterioration as the system ages. Some support for this hypothesis is provided by an analysis of maintenance audits, which show an increasing number of problems being flagged in recent years.

Farm Profitability.

Gross returns to irrigated agriculture have risen steadily in the CBP over the past 30 years. Although information on net returns is sketchy, there is some indication that real net returns have also risen.

Water assessment levels have fallen by about one third since districts assumed management responsibility. This is estimated roughly to comprise about 15 percent of the average farm income.

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CHAPTER 6

Conjunctive Use of Canal Water and Groundwater in Punjab, Pakistan: Management and Policy Options

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OBJECTIVES

THIS PAPER HAS two main objectives:

- To identify current trends in conjunctive use of canal water and groundwater, and their implications for sustainability of current levels of agricultural performance.
- To identify future research needs and management options that will be required for sustaining irrigated agriculture in Pakistan in the future.

A special focus of the study was to utilize as far as possible the existing data sets collected by IIMI to determine what research directions might be appropriate in any continued investigation into conjunctive use of surface water and groundwater in Pakistan.

This approach was adopted primarily for two reasons. First, data collection in the field is expensive, and there is a considerable opportunity cost in using existing data sets. Second, field data collection is time consuming, and frequently, there is pressure to produce output more rapidly than is normally possible with a more traditional approach to field investigation and research. At the same time, the approach which has been used has some limitations, and these must be understood in any effort to place this study in an appropriate perspective.

The first limitation is that most of the existing data sets were not collected for the specific purpose of understanding conjunctive use; rather, they were usually generated for other purposes. Thus the data available from each site were not necessarily compatible; nor was the same range of data always collected in the same manner. A second constraint was that the data collection programs of other research projects did not necessarily cover the complete range of variables that would be desirable for this study. Hence there is a general absence of any economic information, a lack of data on farmer practices in sharing water at the watercourse level, and an absence of surveys of farmer perceptions about the relative utility of surface water and groundwater supplies and the cropping choices that result from these perceptions. Lastly, the data are not fully representative of the range of surface water and groundwater conditions found in the Punjab; they refer primarily to areas where there is good to medium quality groundwater according to the classification scheme used in Pakistan, and reasonable but not optimal surface water deliveries.

The data utilized in this paper result from the salinity and groundwater studies undertaken by Kijne, Vander Velde and Johnson (Kijne and Vander Velde 1992; R. Johnson 1991; Vander Velde and Johnson 1992), the surface water studies undertaken by Vander Velde, Murray-Rust and Bhutta (Murray-Rust 1988; Murray-Rust et al. 1992; Vander Velde 1991; Vander Velde and Bhutta 1992a and 1992b), and the study on late irrigation of wheat done by Bhatti and Wolf (Bhatti et al. 1988 and 1989). All of these studies were supported by funding provided by the Government of the Netherlands and/or USAID.

THE ROLE OF GROUNDWATER IN PAKISTAN

Although modest in relation to the average annual canal withdrawals of about 129 billion cubic meters, the annual useable groundwater recharge in the Indus Basin is estimated to be about 29 billion cubic meters, or slightly over half of the average annual recharge to the aquifers which underlie the Indus plains.³³ As shown in Table 6.1, agriculture in Punjab Province has access to the largest portions of both surface water and groundwater.

Table 6.1. Pakistan: Average annual canal withdrawal and usable groundwater recharge.

Province	Canal withdrawal		Useable recharge *	
	(billion m ³)	(million acre-feet)	(billion m ³)	(million acre-feet)
NWFP	7.5	6.1	1.5	1.2
Punjab	66.4	53.8	24.1	19.5
Sindh / Balochistan	55.2	44.8	3.3	2.7

* Salinity < 1,500 mg/l

Source: WAPDA 1990, pp 3-4 and 3-33.

Conjunctive use of canal water and groundwater has become the lifeblood of irrigated agriculture throughout much of the Indus Basin. Following the first experiments with tubewells for water-table control in the 1950s and the subsequent implementation of the large-scale public sector Salinity Control and Reclamation Project (SCARP) in the 1960s, there has been a virtual exponential growth in groundwater development, especially in Punjab. The significance of the expanded role of groundwater in Pakistan's irrigated agriculture can be readily grasped from a simple, straightforward comparison of the design expectations of the original canal system with current reality.

From the first phase of coordinated canal designs in the late 19th century, areas served by perennial systems in Pakistan were expected to have annual cropping intensities ranging from 50 percent to 75 percent, two thirds of which were to occur in the winter (*rabi*) and one third in the

³³ Useable recharge is defined by Water and Power Development Authority (WAPDA) as groundwater of a salinity level less than 1,500 mg/l. To this total, another 6.7 billion cubic meters of annual groundwater recharge exceeding that salinity parameter, but remaining less than 3,000 mg/l, could be added. These salinity parameters, used by WAPDA to define "fresh" and "marginal" water quality, are equivalent to 2.3 dS/M and 4.7 dS/M, respectively. For most authorities, however, the more generous definition of useable recharge would be qualified by various caveats regarding its use in irrigated agriculture.

summer (*kharif*). In other words, for half the year, it was intended that no more than one half of a canal command would be irrigated, while in the other half merely one sixth to one fourth of the service area would be planted to irrigated crops. Although some farmers could and do achieve higher cropping intensities than this using surface water alone, rarely are they able to exceed 100 percent for the year, and that usually is achieved at the expense of farmers in tail-end commands who get little or no canal water at all for much of the year.

With extensive groundwater exploitation, however, cropping intensities in the Punjab canal commands now commonly exceed 125 percent, increasing to over 150 percent in some watercourse commands. For more limited extents of canal service areas, groundwater sustains permanent crops, the intensive cultivation of fruits and vegetables, or other short-duration, high-value crops that can be harvested two or three times in a year. For large areas of the province, however, there is mounting evidence that as a result of current levels of groundwater pumping, water tables have dropped so far that opportunities for further increases may be severely limited (NESPAK-SGI 1991).

Most of the groundwater exploitation in Pakistan is done in the context of conjunctive use with surface water. Irrigated agriculture using only groundwater is limited to mainly three situations: gaps in the canal systems of the Indus Basin where surface water has not been made available, small systems outside the Indus Basin, and small systems in the tail reaches of canal commands that have lost access to surface water through inequitable distribution of canal water supplies. The vast bulk of the most productive areas of the Indus Basin, and Punjab in particular, are those where there is conjunctive use of canal water and good-to-medium-quality groundwater. Only where groundwater is highly saline is there a reliance on canal water deliveries for sustaining irrigated agriculture.

To understand the dynamics of the current situation, it is useful to briefly review the way in which groundwater development has occurred in Pakistan over the past thirty years.

UNDERSTANDING CONJUNCTIVE USE

Virtually all of the surface irrigation systems in Pakistan's Punjab were developed within the framework of the North India Canal Act of 1873. This act institutionalized the concept that water allocations would be insufficient to meet the full potential crop water demand over all of the area developed with irrigation facilities. During the following decades, a method of sharing water by time also emerged and became codified. This system, known as *warabandi*, was developed in order to allocate a scarce resource as equally as possible between as many farmers as possible and to simplify subsequent administrative requirements. In practice, there are two distinct types of *warabandi* — either sanctioned by the Irrigation Department (so called *pucca*), or nonsanctioned by the government but locally agreed upon (*kaccha*) — with each also characterized by different sharing arrangements and cycles. However, all *warabandis* have in common the basic characteristic of a fixed time and share in irrigation on a timetable that is known to every farmer served by the same watercourse.

Conditions Prevailing Before Groundwater Exploitation

When groundwater is not available, farmers have to make decisions on the area to be irrigated during each *warabandi* turn: some crops might be irrigated every turn, others only once every two or three turns. Although there are some opportunities for buying and selling water out of turn, these

are likely to be limited because all farmers face the same potential water deficit. Farmers are only likely to sell part of their turn if they have cultivated less than their full potential, or if the potential profit from selling water appears especially attractive.

Historically, a little groundwater development had occurred in parts of the Indus Basin through dug wells to which primitive water lifting devices were subsequently added, or later still, with animal power being harnessed (e.g., the Persian Wheel). This was generally restricted to such locales as riverine terraces where water tables were favorable, and even with the advent of the Persian Wheel, well irrigation remained slow, costly and limited in command area.

Public Deep-Tubewell Development: 1950–80

Modern groundwater development in the Indus Basin occurred primarily through publicly financed and operated deep tubewells. These tubewells were invariably electric powered, with multi-stage turbine pumps in the bore itself, and designed to deliver about 85 l/sec.

In Pakistan's Punjab, several experimental attempts by the government were underway in the 1950s to use deep tubewells either to reduce water tables in waterlogged areas or to increase supplies of water for irrigation. By the early 1960s Pakistan had embarked upon a large-scale program of deep-tubewell development, the SCARP, primarily to combat widespread waterlogging and associated salinity. Over the past 30 years, more than 12,500 public tubewells have been installed nationally through various SCARP projects. An important, initially secondary, objective of this program was surface water supplementation by public wells, usually discharging directly into the existing watercourse network where groundwater was classified as suitable for agriculture.³⁴ The resulting conjunctive use of canal water and groundwater did not change the basic approach to irrigation through a time-based roster of turns, the warabandi. Rather than providing greater flexibility in access to water, the primary effect of the public tubewell was to augment the discharge in the watercourse.

Public tubewells, notably those pumping water defined as fit for irrigation work in SCARP schemes, are supposed to operate according to schedules developed by the Irrigation Department. The schedules are intended to conform to broad guidelines concerning the target percentage of annual capacity and the time of operation. For various reasons both guidelines and operating schedules have ceased to have much relevance to actual public tubewell operations (S. Johnson 1982).

The institutional setting is sufficiently complex that it has become difficult to achieve much coordination. The SCARP wells were installed by WAPDA and operations are controlled by a division of the Irrigation Department that is independent of the division that handles canal operations and drainage. The actual operation of the public tubewell is under the (presently nominal) control of an operator, a low-level irrigation department employee in the tubewell operations unit, whose job is to turn the tubewell on and off according to schedule, including the requisite four-hour "rest" period, to keep the equipment functioning as well as possible, and to maintain a logbook of well operations. Tubewell maintenance and repair is carried out by a separate maintenance unit within each tubewell division. In theory, there was no role for farmers to play in public tubewell O&M; in practice, farmers have become the operators of most public wells as well as active in organizing their maintenance.

Not all farmers benefitted equally from this type of groundwater development; real equity in access to water pumped by public tubewells can only occur when they are located at the head of

³⁴ Over 11,000 SCARP tubewells are classified as pumping fresh groundwater (WAPDA 1988).

the watercourse. Often, public tubewells are located elsewhere within a watercourse command area so that only those farmers downstream of it are able to benefit. Additionally, some tubewells serve parts of two or more watercourse commands; in other cases, siphons carry part of the tubewell discharge across distributaries; and other wells serve areas both outside the canal command and within it. Hence, local arrangements for accessing public tubewell water are often relatively complex. In certain instances, some farmers may have both a canal-water warabandi and a separate tubewell-water warabandi, while others have a single turn that mixes tubewell and canal water, and still others have a turn on tubewell water but remain outside of the canal-water warabandi.

Private Shallow-Tubewell Growth: From 1970 to Date

There is no doubt that with the development of the SCARP tubewells for irrigation purposes, growing numbers of Pakistani farmers have become accustomed to, and have increasingly desired greater access to groundwater to supplement their surface water deliveries. With the development of less expensive diesel engines and centrifugal pumps, modern shallow-tubewell technology has emerged as a viable option for groundwater exploitation.

Beginning in the 1970s, assisted by government programs that encouraged private-tubewell development, the entire situation of groundwater exploitation has changed (R. Johnson 1989). Individual farmers have found it relatively easy to invest in small pump and engine sets capable of delivering 15–30 l/sec. With the equipment sited on the surface rather than sunk in the well, the borehole drilling costs are modest and maintenance of both pump and motor is comparatively easy.

More than 300,000 private tubewells are installed in Pakistan today, and many farmers in Punjab now have access to three distinct sources of water for irrigation: canal water according to the original warabandi, groundwater from deep, public tubewells according to the local schedule followed, and groundwater from privately owned and operated shallow tubewells. Where these conditions exist, farmers generally have access to irrigation more or less at any time they want. They can trade water more easily, either through buying and selling or on some other basis; and they can move water across previously impermeable watercourse command boundaries. In short, large parts of the Punjab Irrigation System have become a complex conjunctive management environment.

CONJUNCTIVE USE: SUBSTITUTION OR COMPLEMENTARY USE?

A critical aspect of conjunctive use which must be thoroughly understood is that *groundwater and surface water are not necessarily exchangeable on an equal basis*. This situation only occurs when their price is essentially the same and where water quality does not threaten yield or soil deterioration. Where there are price or quality differences, the farmers have to make tradeoffs between the sources of water.

In one typical situation of conjunctive use that was examined in IIMI's program in Indonesia, groundwater is being used to supplement shortfalls in surface water supplies. Tail-end farmers may, albeit at additional cost, attain cropping intensities at or close to those of head-end farmers who have more than sufficient surface water. Pumping will occur during periods of peak demand to ensure that crops do not suffer drought, but the entire groundwater irrigation system in this situation is supplemental to the surface system. During the wet season, there is no pumping and it is usual to find pumping only for short periods during the dry season.

By contrast, in Pakistan, groundwater is not commonly used to meet temporary shortfalls in supply. Groundwater often constitutes a high percentage of total water used conjunctively in irrigated agriculture in many canal commands, and the agricultural pattern is completely dependent upon the ability to pump for extended periods of time.

Conventional Wisdom on Conjunctive Use in Pakistan

Early in 1991, Pakistan's four provinces finally reached agreement on the apportionment of the water resources of the Indus River System (Badruddin 1991). This accord and the extensive Water Sector Investment Planning Study (WAPDA 1990) which preceded it have placed Pakistan's groundwater resources more prominently on the national resources map. While, for many years, the contribution of groundwater to irrigated agriculture went largely unrecognized in terms of the planning of overall water resources, it is now acknowledged as being of considerable importance. However, the views which have developed about how it is used still require examination.

Conventional wisdom in Pakistan requires that farmers use groundwater primarily to supplement water received from the canal system — except, of course, in those areas outside the canal command — and it is likely that this view was largely shaped by the SCARP experience.³⁵ This view is rather neatly reinforced by further rationalizing that although it is unfortunate that canals no longer deliver water equitably along their length, everything turns out all right in the end, because farmers can and do use groundwater instead, mostly derived from canal system losses, to make up for the deficit.³⁶ True, it is acknowledged, this places an additional financial burden on farmers in areas with poorer supplies of surface water due to the cost of groundwater extraction, but that is or will be offset, at least to society at large, through increased overall water use efficiencies.

A second, still evolving concept in some quarters of Punjab is that there are even possibilities of "saving" surface water due to the high level of groundwater use in fresh groundwater areas. It is thought that this saving of surface water can be achieved through an extensive program of canal lining, which reduces seepage losses and allows slight reductions in allocations to lined channels. The quantum of water thus saved will offset surface supplies "lost" in the 1991 apportionment accord, with the further possibility that more water then can be directed to areas where groundwater is saline.

In some contrast to these two interrelated views is the knowledge emerging in IIMI that even where farmers rely heavily on groundwater for agriculture, their decision making remains strongly influenced by their relative access to surface water. There are two sets of reasons that underpin this line of argument. The first is that surface water in Pakistan is of superior quality and, in practical terms, it is nearly free. The second is that surface water supplies are relatively more predictable than groundwater; they are not subject to sudden termination due to mechanical breakdowns or power failure. In short, a little good quality surface water goes a long way in helping farmers decide what to grow, when to grow it, and how much of it to grow.

A major objective of this study, therefore, has been to determine whether or not such relationships exist between the water source and cropping decisions made by farmers. If they do,

35 "The main incentive necessary for (private groundwater development) appears to be the farmers' demand for more water which cannot be fulfilled by other means . . ." (WAPDA 1990:3-37).

36 "(Fresh groundwater) does, however, offer considerable potential for supplementary supplies when surface supplies are short." (WAPDA 1990:9-9).

then there should be a marked spatial dimension to groundwater utilization and agricultural patterns that is closely related to the relative location within the distributary canal system.

The policy implications of such findings are important. If farmers freely substitute groundwater for surface water, then a policy to redistribute surface water within and between canal commands to mitigate and manage salinity could be pursued without any serious impact on cropping. On the other hand, if farmers continue to make decisions based upon their access to canal supplies, then it is likely that there will be significant cropping pattern changes in response to surface water redistribution.

Somewhat surprisingly, there has been little effort to date in Pakistan to determine which of these scenarios is more likely to be true. Thus, it is useful to look at two aspects of groundwater exploitation that may be reasons for farmers to use water differently than suggested by conventional wisdom.

Groundwater Quality and Reliability

In this context, there seem to be two key areas in a farmers' irrigation decision-making matrix where information and a capacity to use it effectively are critical: difference in *quality* of available surface water and groundwater, and *total water availability* in the period of peak demand in each season.

Quality

In quality terms, it is readily apparent that surface water and groundwater supplies are not simply exchangeable. Whether the bulk of available irrigation water is fresh or saline makes a great difference in basic cropping choices. Some crops are particularly sensitive to salinity, and thus cannot be productively cultivated if only poor quality irrigation water is available. Therefore, in conjunctive use environments where surface water is of good quality but relatively less abundant, and groundwater is of poorer quality but relatively more abundant, most farmers are likely to seek to mix groundwater with as much surface water as possible to maximize their irrigated area. This, in turn, implies that the availability of greater quantities of surface water also favors a greater use of groundwater, an additive rather than a simple substitution relationship of one for the other. If this is so, then total irrigation water use trends should reflect general surface water trends, rather than being essentially neutral to location as would be the case if groundwater was simply being used as a substitute for canal water.

Reliability

The second factor, water availability, is probably directly related to reliability. Surface water supplies, particularly in the head reaches of canals, are highly reliable in the sense that water is almost always available. There are differences in the volume delivered on a day-to-day basis, and these can be quite large, but there is a strongly positive relationship between discharge received on one day and the probable discharge delivered on the next. This means that both short-term and long-term decision making is comparatively straightforward, and cropping decisions in areas where only surface water is available seem comparatively easy to predict and explain.

Pump-based irrigation requires a different assessment of reliability. When a tubewell — whether deep or shallow — is operating, the discharge is nearly uniform. But uncertainty tends to

enter during the time of operation. One concern is mechanical unreliability: a tubewell and pump set can break, so that no more water is available until the equipment is repaired. In the case of a major breakdown in a deep tubewell, such as the burnout of electric motor windings or repairs that need to be done to the turbine in the bore itself, it is not uncommon for farmers to immediately abandon part of their crop. Shallow tubewells repairs are easier, though not necessarily easy, but the owner usually requires cash in hand or a willingness to incur a debt to get the repairs done quickly.

The second cause of groundwater unreliability is an unreliable tubewell power supply. Virtually all public tubewells and approximately 15 percent–20 percent of private tubewells are electrically powered.³⁷ Unfortunately, electricity in Pakistan continues to be a highly variable commodity, both in terms of supply and voltage. Power cuts — scheduled and unscheduled — have been and remain a common occurrence for the rural feeder lines that supply power to tubewells during the two months of greatest irrigation demand and during periods when crop water needs are low.³⁸

Electric power operations data for several weeks during the 1989 kharif season for the two feeder lines that serve 25 of the 30 watercourse commands of the Lagar Distributary illustrate the problem faced by farmers using electric tubewells to pump groundwater (Figure 6.1). On average, these feeders were off two-to-three times more hours than that scheduled throughout the period covered by these data; moreover, stoppage of power supply occurred two or three times daily. Field measurements of private electric tubewells recently undertaken by Pakistan's National Energy Conservation Centre (ENERCON) have revealed that line voltages commonly deviate ± 50 volts from the standard, while phase-to-phase differences frequently exceed 5 percent. Both conditions contribute to high rates of electric motor burnout and frequent costly repairs.

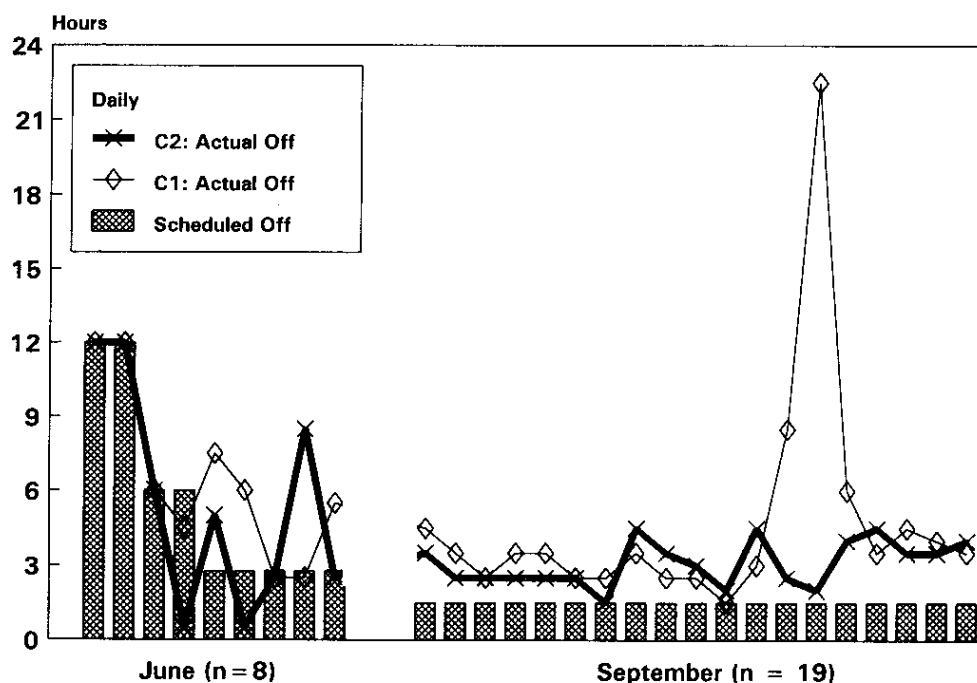
Nevertheless, electric power remains attractive because it can be obtained at a relatively low cost, often at a flat rate regardless of consumption and sometimes even illegally, by tapping transmission lines or bypassing meters in connivance with power agency staff. The ease of electric tubewell operation may also be a factor. While it is true that diesel power is inherently more reliable than WAPDA-supplied electricity, it requires immediate up-front payment, plus fuel transportation from a limited number of supply points, and storage in reasonable quantity at site. Tubewells operated by tractor power take-offs also play an important role. Although cheaper to install in relation to either diesel or electric tubewells, they tend to be a less favored source of groundwater because of their higher operating costs.

In the context of such uncertainties, it is reasonable to hypothesize that access to surface water of good quality and relatively high dependability is likely to influence farmer cropping decisions more fundamentally than access to larger volumes, but poorer quality groundwater obtained through equipment or power sources of dubious reliability. These hypotheses are now examined in the light of the available data.

37 A total of 1,212 private tubewells have been identified in the nearly 50 watercourse commands surveyed by the IIMI field staff in the Lower Chenab Canal (LCC), Fordwah and Eastern Sadqia canal commands by mid-1992. Of this total, 16 percent were electric-powered, 49 percent diesel-powered (either high-speed or low-speed engines) and 35 percent were operated by tractor power takeoff. These figures contrast sharply with the data reported by NESPAK-SGI in their recent Pakistan-wide study of private tubewells; 39 percent of all Punjab tubewells and 45 percent of all wells in Pakistan are identified as electric-powered. No mention is made in this study, however, of tractor-powered tubewells. (NESPAK-SGI. 1991. Final Report, Annex I, pp. 9–11.)

38 Officially, loadshedding ended in Pakistan in mid-1991. However, frequent, often extended disruptions in power supplies continue, especially in rural electric grids. They occur: (1) during the annual canal closure period, traditionally the month of January in the cool rabi season when hydropower generation is purposely reduced in order to minimize non-multi-use water releases from Pakistan's few reservoirs; and (2) in the months of the hot kharif season, when peak crop evapotranspiration rates directly compete with urban dwellers' refrigeration and air-conditioning requirements.

Figure 6.1. *Lagar Distributary Command electricity supply: Load-shedding operations in kharif, 1989.*



Feeder C2 = Head and middle watercourses

Feeder C1 = Tail watercourses

OBSERVED TRENDS OF GROUNDWATER USE AND AGRICULTURAL PATTERNS

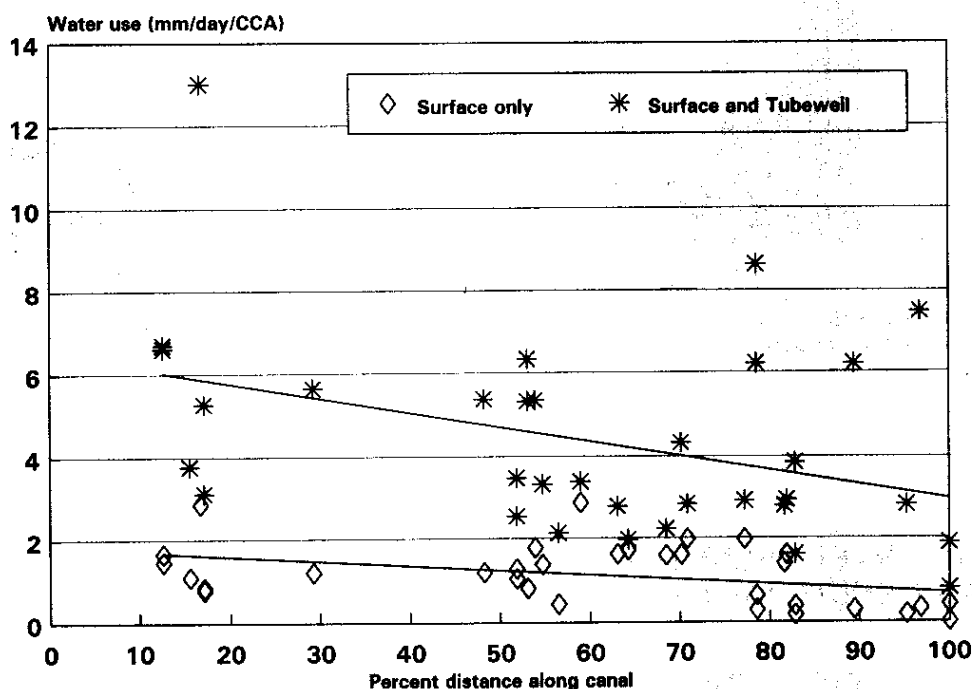
The data collected by IIMI over the past four years from 41 watercourses in four distributary canal commands in the Lower Chenab Canal (LCC) system provide several insights into conjunctive use of surface water and groundwater. Water supply and water quality data were standardized by defining locations in terms of percentage distance along the canal from head to tail; crop data were standardized in terms of proportions of watercourse CCA (Culturable Command Area), the overall area of each watercourse *irrigable by the surface system*. Surface water and groundwater volumes were determined based upon measurements at the outlet, and at the tubewell discharge pipe, respectively; they were not adjusted for within-watercourse and farm-conveyance losses and application efficiencies. The data have been analyzed from two dimensions: the apparent perception of farmers about the likely availability of water that affects the overall pattern of irrigated agriculture, and the farmers' short-term water use response in an environment where there is ample opportunity to pump groundwater to complement surface water supplies.

Broad Patterns of Irrigated Agriculture

In an effort to determine the extent to which farmers are guided by or respond to the availability of different types of water, data were analyzed with respect to the relative location along the distributary. The following broad trends emerged from subsequent analyses:

- Surface water deliveries to outlets decline along canals from approximately 2 mm/day near the head to about 0.5 mm/day at the tail (Figure 6.2). The rate of decline of surface water deliveries is significantly related to watercourse location along the distributary at the 5-percent level, although there is a great deal of variability. When analyzed for individual canals, the decline in access to surface water shows a much greater association with percent distance along the canal.

Figure 6.2. Actual irrigation water available at watercourse level.



Excludes rainfall

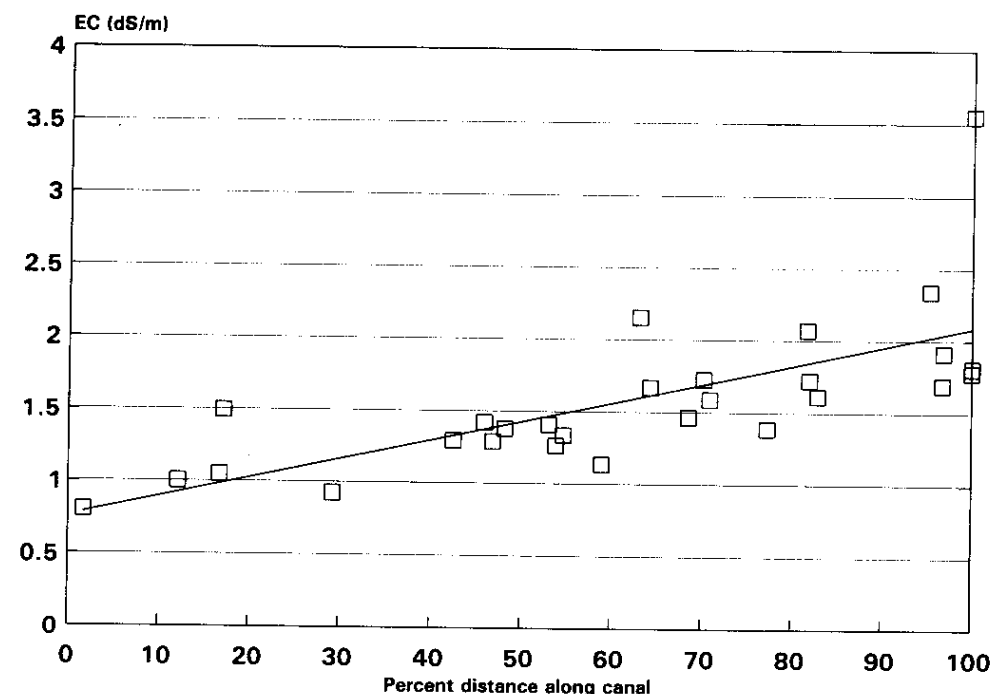
- Total groundwater use also declines along canals from about 4.5 mm/day at the head end to about 2.5 mm/day in the tail-end watercourses. This relationship, however, is not statistically significant.
- Total water use expressed in terms of the overall irrigable area declines from head to tail of the canal. This relationship is statistically significant at the 5-percent level.

This means that the percentage of groundwater in the total quantity of irrigation water used by farmers increases along the canal, from roughly 65 percent at the head to 85 percent at the tail.

Accompanying the decline in access to surface water and an increased dependence upon groundwater is a dramatic decline in groundwater quality from the distributary head to the tail:

- Average electrical conductivity (EC) for each watercourse increases from about 0.9 dS/m at the head to 2.1 dS/m at the tail (Figure 6.3). These figures are based upon water quality measurements from all tubewells in each watercourse, typically in the range of 10 to 30 wells. Thus many farmers are using groundwater which is very poor in quality (up to 4.0 dS/m, a salinity level that severely affects crop production).

Figure 6.3. Average tubewell-water quality in watercourses.



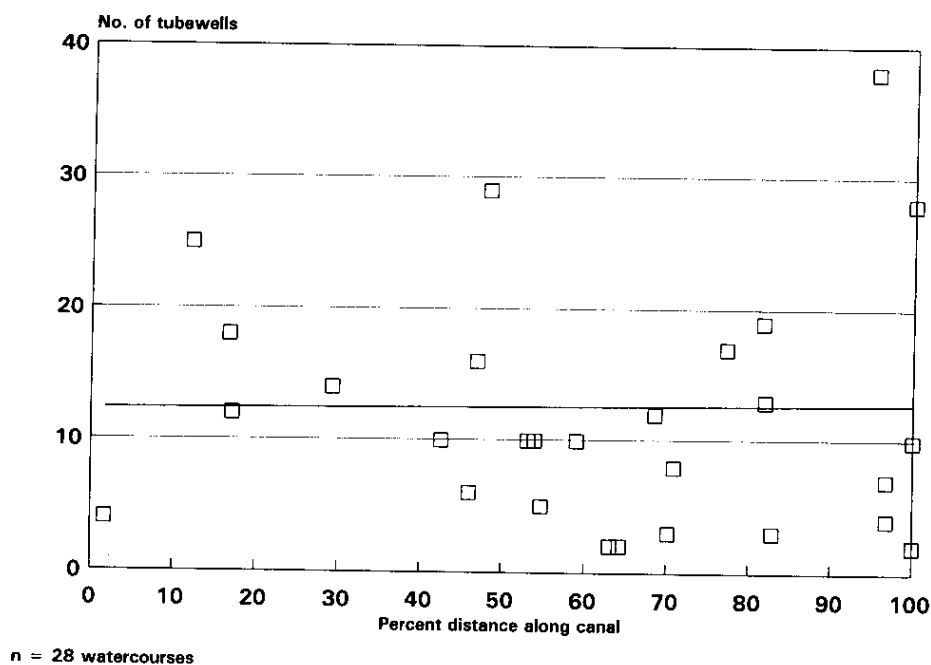
n = 28 watercourses

- Sodium Absorption Ratio (SAR) increases in exactly the same pattern, from 2 at the head to about 14 in the tail-end watercourses.

Both water quality measures show the same rate and direction of change within canal commands, at levels of significance exceeding 1 percent, and the relationship is persistent despite the wide geographical spread of the data.

Despite these two factors — decreased water use and declining water quality — there is no apparent relationship between canal location and density of tubewell installation. In the Lagar Distributary, for example, where a complete tubewell census was taken, there is no visual indication of a spatial pattern of tubewell installation (Figure 6.4), and this observation is borne out by data from several different watercourses in other canal commands (Figure 6.5).

Figure 6.5. Number of tubewells per watercourse.



Despite these trends, there are significant differences in water utilization rates between watercourses, and from one time of the year to another. The range of conditions is illustrated for three watercourses in the Lagar Distributary Command: a head-end watercourse (2R) that has design levels of surface water supplies and high rates of groundwater use, a watercourse near the middle (9L) that has adequate surface water but highly seasonal pump utilization, and the tail (21TL and 22TF combined) which has marginal surface water deliveries and, at least in the summer, is completely dependent on groundwater for agriculture (Figures 6.6, 6.7 and 6.8).

The agricultural consequences of these conditions are clear and consistent across the two study areas in the resulting summer and winter cropping patterns, and are readily explained by important differences in conjunctive use between the two seasons.

Summer Cropping Patterns

The summer season in Pakistan is hot, frequently humid in the middle months, and thus ideal for growing rice. In some locales, cotton is a major acreage competitor, but the study areas do not cover any of Pakistan's main cotton growing regions. Based on Figure 6.9, the following observations can be made:

Figure 6.6. Summer (kharif) cropping intensity.

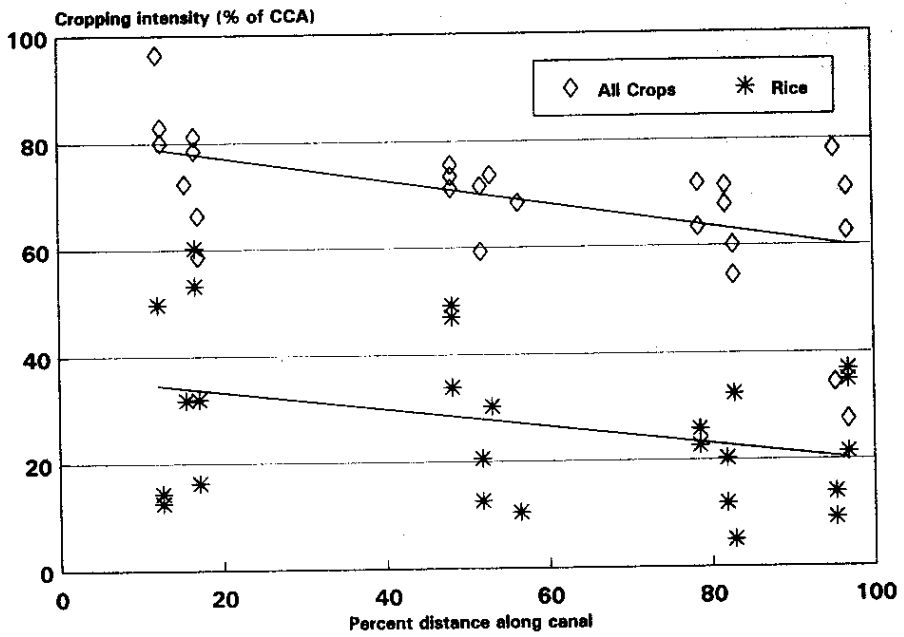


Figure 6.7. Winter (rabi) cropping intensity.

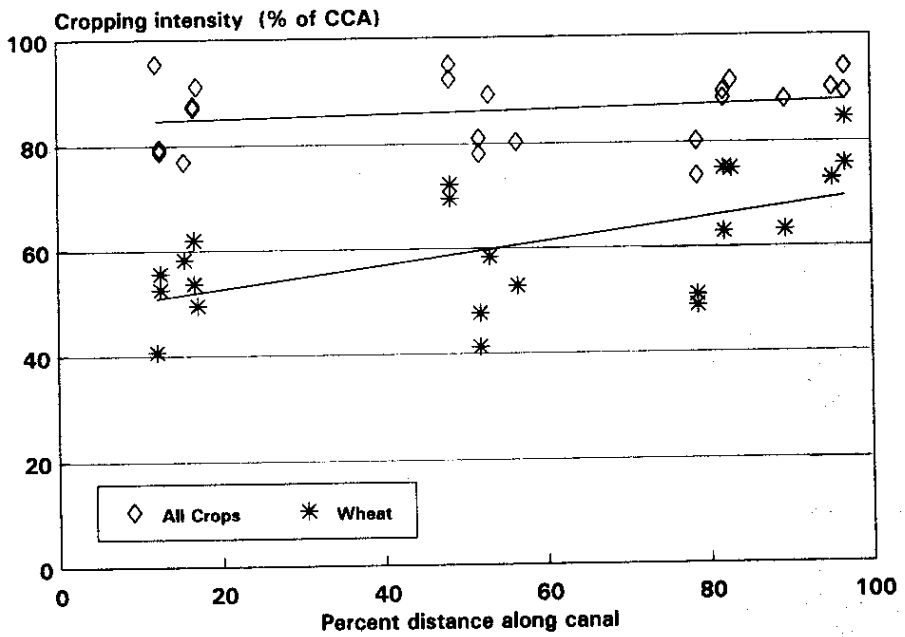
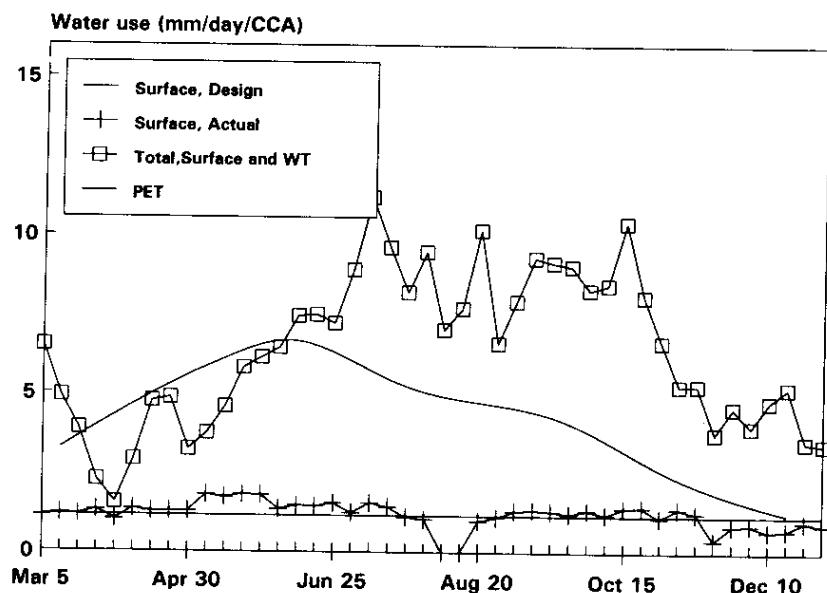


Figure 6.8. Surface water and tubewell water use: Watercourse 3R, Lagar, 1989.

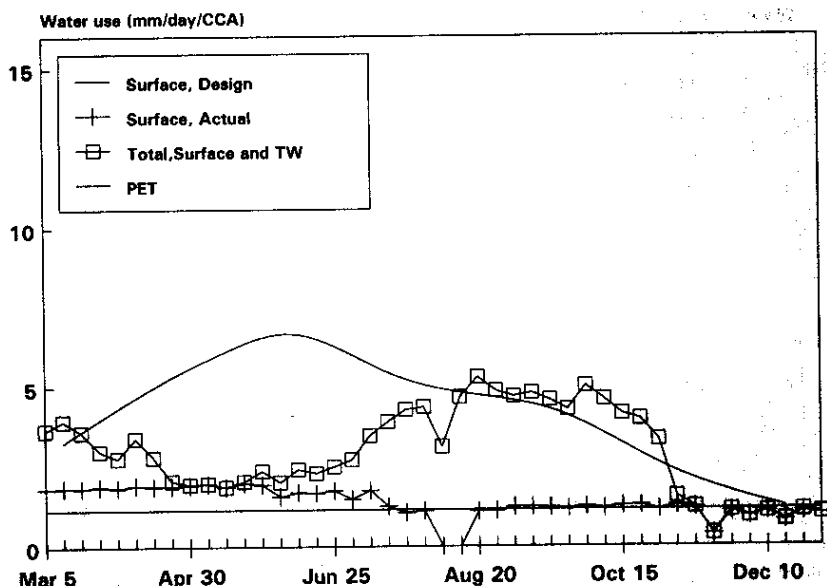


Notes: PET = Potential evapotranspiration
TW = Tubewell

- Cropping intensities (the percentage CCA cropped) drop from 80 percent in head-end watercourses to about 60 percent at the tail. This change is clearly mirrored in the decline in total irrigation water use from the head (6.5 mm/ha CCA/day) to the tail (3 mm/ha CCA/day), on average, from 1 July to 30 September).
- Cropping patterns reflect the change in overall irrigation water supply: the area under rice drops from nearly 40 percent of the CCA at the head-end watercourses to about 20 percent at the tail. A similar relationship is observed for other commercially important crops: cotton declines from 13 percent to 9 percent, sugarcane from 12 percent to 7 percent, and even orchards show a slight decline, from 3 percent to 1 percent. Farmers partially compensate the declines by growing more fodder; fodder has increased from 14 percent to 20 percent of the tail-watercourse CCA.

There is no evidence in the data that kharif cropping patterns are spatially neutral. The parallel trends of surface-water deliveries to watercourses and downstream declines in groundwater quality, thus strongly support the hypothesis that availability of surface water continues to influence the cropping patterns. It is obviously very expensive to cultivate rice using only pumped water, particularly when evapotranspiration is close to 7 mm/day. This helps to explain the huge increase in canal water theft between June and August, a phenomenon which decreases as evapotranspiration decreases.

Figure 6.9. Surface water and tubewell water use: Watercourse 9L, Lagar, 1989.



Notes: PET = Potential evapotranspiration
TW = Tubewell

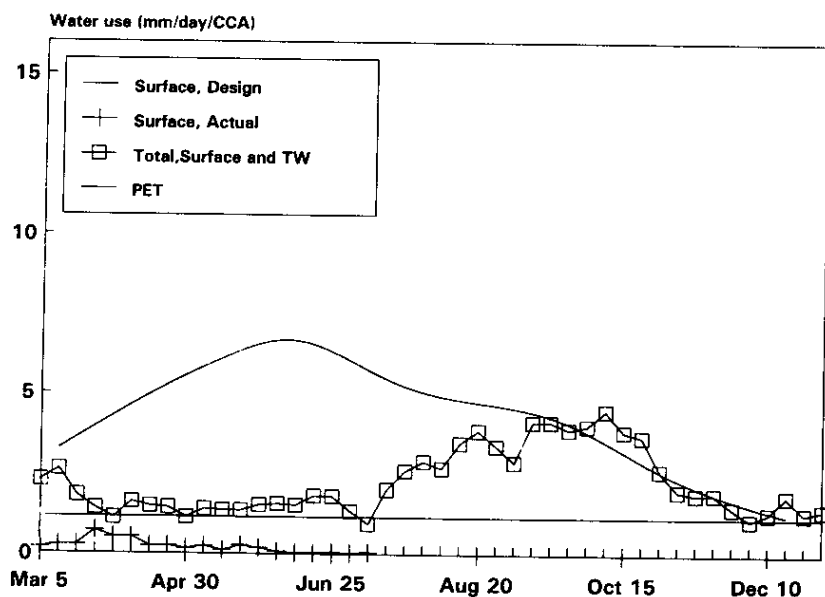
Winter Cropping Patterns

The situation in winter is completely different, reflecting the changed balance between water availability and demand. The main observations (Figure 6.10) are:

- Cropping intensities show no relationship to location along the canal (they actually increase marginally down the canal), and are very high, averaging 85 percent of CCA.
- The area planted to wheat increases dramatically downstream of the distributary, from 50 percent of CCA at the head, to 70 percent at the tail, a relationship that is statistically significant at the 5-percent level.
- Sugarcane and orchards show the same trend as in the summer, because they are annual or perennial crops; there is a marginal decline in both from head to tail watercourses, and in total they occupy about 12 percent of CCA.
- The balance cropped area is made up of fodder and vegetables. Vegetables are of high value, but also highly vulnerable to salinity, thus farmers who must use much poorer quality groundwater normally will not grow vegetables.

The pattern found in winter is readily explained by water availability in relation to demand. Surface water delivery rates at the tail end are more or less at design (1.2–1.7 mm/day), which approximates evapotranspiration. Groundwater use, therefore, is significantly less than in the summer, both in terms of the total amount and the percentage used. As evapotranspiration increases

Figure 6.10. Surface water and tubewell water use: Tail watercourses (21 and 22), Lagar, 1989.



Notes: PET = Potential evapotranspiration
TW = Tubewell

during the latter part of the wheat crop, pumping of groundwater also increases indicating that some measure of late irrigation is practiced in response to actual crop water requirements.

Only in areas where groundwater quality is reasonable and market access favorable is groundwater likely to be pumped in large quantities during periods of relatively low evapotranspiration, because these locations are advantageous for intensive vegetable cultivation. Indeed, in such locales, land too high for surface irrigation, the gross command but not CCA, has often been brought under cultivation by groundwater development.

Water Use per Irrigated Area

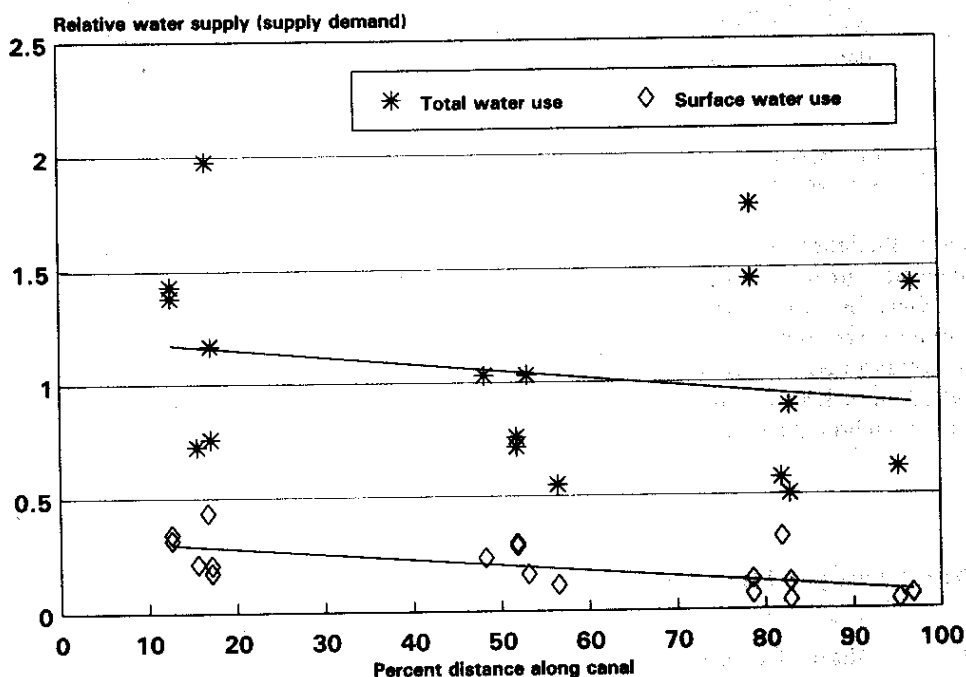
The data indicate that once farmers have made basic decisions about the area to be cropped and the range of crops to be grown, they then use water relatively efficiently. This is demonstrated by the actual water utilization rates for the peak period during kharif, July to September. In head-end watercourses, the average total irrigation water use is about 6.5 mm/ha/day (surface water at 2.0 mm/ha/day and tubewell water at 4.5 mm/ha/day), with a cropping intensity of 80 percent. This means that the rate of irrigation water delivery is around 8 mm/ha/day for the *actual* cultivated areas, compared to an evapotranspiration rate averaging 4.85 mm/day. If the average crop-water requirement is more or less equal to evapotranspiration during the summer months, and an additional requirement of 5 mm/ha/day is included for seepage and percolation in areas planted to rice, the total water requirement is about 7.5 mm/ha/day. Excluding the effects of rainfall, therefore,

the overall relative water supply for irrigated areas is about 1.07, indicating that farmers are not pumping, appreciably, more water than they need (Figure 6.11).

Using similar estimates of crop coefficients and seepage and percolation rates for the tail-end watercourses, the total water requirements for actually irrigated areas are about 6.5 mm/ha/day. The *actual* irrigation water deliveries to the cropped area are nearly the same (6.0 mm/ha/day tubewell water and 1.0 mm/ha/day canal water) as in head-end areas, so that relative water supplies are again close to 1.0.

Effective rainfall during this period averages 4 mm/day, so that the total water supply for the irrigated area is 12 mm/ha/day. With demand at about 7.5 mm/ha/day, the relative water supply then increases to 1.5. However, rainfall is uncertain even during this season, and rice must often be planted before the main rains have become established. Because rice is an important component of the cropping pattern in all of the sample areas, and because rice yields drop rapidly if there is drought-induced stress, it is logical for the decision on how much rice to plant to be based on the expected availability of dependable surface water and tubewell supplies rather than guessing on likely rainfall during the months ahead.

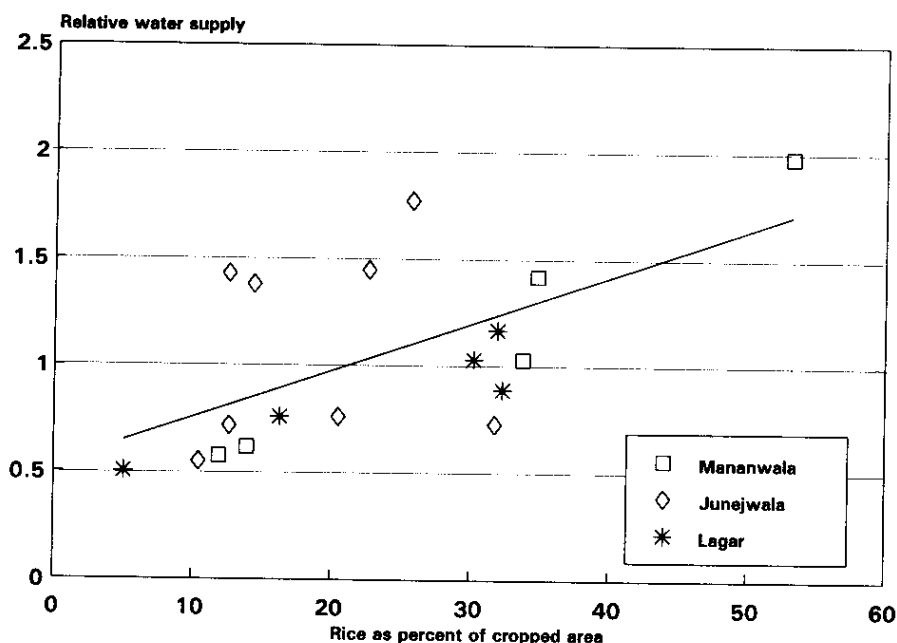
Figure 6.11. Irrigation water use: Watercourse-level supply and demand.



Excludes rainfall

The importance of rice in the cropping system is seen by analyzing irrigation water use in the summer months (Figure 6.12). When more than 30 percent of the cropped area is under rice, the relative water supplies increase from more than 1.0 up to nearly 2.0 when rice exceeds 50 percent of the cropped area. Conversely, as rice declines in importance, the relative water supply also drops. This relationship strongly suggests that farmers are fully conscious of the different water requirements of rice and other crops. If the relative water supply for rice drops much below 1.0 at

Figure 6.12. Irrigation water use and rice cultivation.



the field level, yields will decline rapidly, but for most other crops when the relative water supply is less than 1.0, yields decline more or less in proportion to the degree of crop stress.

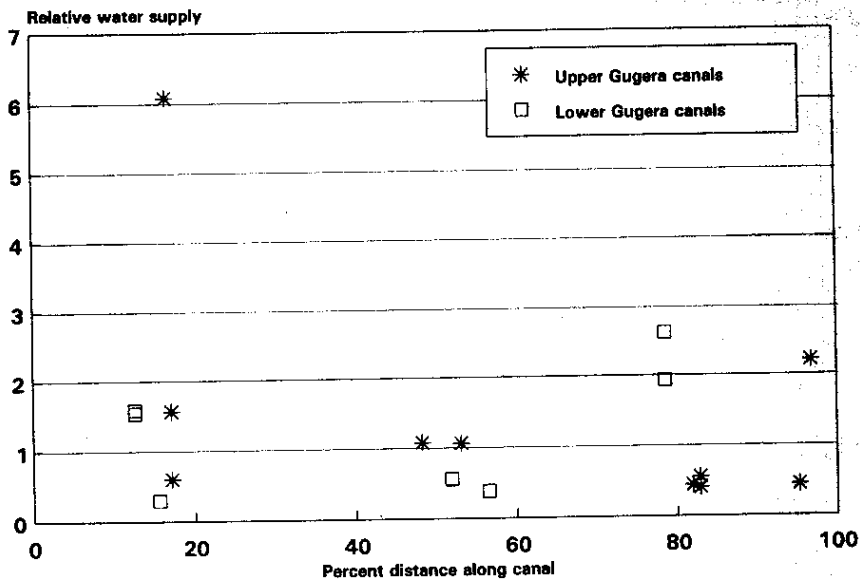
If the assumption is made that rice is normally given sufficient water to avoid stress, (*i.e.* at a relative water supply of 1.0, or 10 mm/day in the study area), the relative water supply for all other crops also can be calculated. The results, expressed here in relation to distance, suggest that despite the high proportion of groundwater use, the relative water supplies in tail-end areas are about 0.5, rising as expected to about 1.0 at the head (Figure 6.13).³⁹

The very close values of the kharib season relative water supply for the head and tail watercourses in all sample canals strongly suggests that throughout these areas farmers are using groundwater conjunctively to meet crop-water requirements with some precision. However, it is important to also include a leaching requirement in the calculation if secondary salinization is to be avoided, even more so in the tail reaches of distributaries.

Groundwater EC in the tail-end watercourses averages 2 dS/m and exceeds 3 dS/m in many wells; under these conditions the leaching requirement is quite high. An application of 2.5 mm/ha/day of water with an average EC of 2 dS/m means that the total amount of salt applied at the soil surface is very high. A daily water volume of 25m³ per hectare with a dissolved salt load of 1,250 ppm means that approximately 32 kg of salt is applied per hectare per day. Given the actual relative water supply values found for these areas, it is not surprising that secondary soil salinity is building up rapidly, and it is only with adequate rainfall that any significant leaching is likely to occur.

³⁹ The authors are grateful to Gil Levine for his insight into the use of relative water supply in understanding farmer irrigation practices in this context.

Figure 6.13. Irrigation water supply for nonrice crops.



INTERPRETING THE FINDINGS

The overwhelming conclusion that can be drawn from these findings is that farmers' kharif season cropping choices, in terms of both the total area cultivated and the crop-mix, are closely linked with the relative location of their watercourses along the distributary. There appear to be two possible explanations for this:

- Farmers are influenced in their cropping decisions by the deterioration in groundwater quality downstream, within the canal commands, and relatedly along the watercourses.
- Farmers are influenced by the relative access to good quality surface water rather than by the ready availability of groundwater when making crop choices.

In reality, it may not be possible to differentiate which of these two explanations is operative for most farmers. However, it seems clear that the phenomenon of secondary salinization is closely linked to the process of irrigation subsequently being practiced by these farmers in the LCC system. Furthermore, if the data presented here are reasonably representative of water use rates elsewhere in Pakistan's Punjab, then it is probable that the high percentage use of poor quality groundwater in tail-end watercourses is a major, if not primary, contributor to the rise in secondary soil salinity towards the tails of distributaries.

In summer, especially early summer, evapotranspiration rates are extremely high. If plants use most of the available water for growth, then the residual moisture in the soil will inevitably

have a higher salt content than that of the irrigation water being applied. Because groundwater quality and water use are higher in head-end areas, however, the development of secondary salinity there will have been less than that in the tail-end areas in the past two to three decades of groundwater exploitation.

Just how farmers could be so sensitive to the relatively gradual decrease in groundwater quality along each canal remains a puzzle. It is true, of course, that when salinity has reached a certain level it is possible to detect its presence without sophisticated equipment: soils may show salt residues on the surface, or tubewell water may taste brackish. Before that point is reached, however, salinity may be affecting both crops and soils, but in a more insidious, less obvious manner.

If the two conclusions, that (1) a primary cause of decreasing groundwater quality downstream in distributary commands is the greater proportion of its use relative to surface water to meet irrigation requirements, and (2) that secondary salinity is largely a consequence of present conjunctive irrigation practices characterized by high water use efficiencies are correct, the implications for sustainable irrigated agriculture in Pakistan's Punjab are ominous.

Two sets of options are proposed below that may guide policymakers towards determining what course to take in the future in efforts to sustain irrigated agriculture in Pakistan. They are divided into short-term and long-term options.

Short-Term Options

The short-term options all revolve around the principle of redistribution of existing water supplies to counter the current trends towards increasing groundwater and soil salinity. They are based on the various policy options included in the national Water Sector Investment Planning Study referred to in the section on "Conventional Wisdom on Conjunctive Use in Pakistan" (p.166).

- *Present trend:* Farmers in watercourses in the upper half of distributaries continue to capture greater percentages of surface water to maintain their current cropping patterns; in lower-reach watercourse commands, increases in salinity and decreases in kharif cropping intensities continue and farmers are becoming poorer.

Realistically, given the research findings reported herein, it is difficult to conceptualize approaches to the problem that would reduce the overall potential for increased salinization. For example, events following efforts to reallocate surface water within a distributary canal command with both a significant decline in groundwater quality and an increase in secondary soil salinity from head to tail might well look like this:

- *Intervention:* Deliver less water to canal head-end watercourses and redirect flows to tail-end outlets; water distribution equity is restored in the canal and/or reverse inequity is established.
- *Probable response:* Head-end farmers refuse to accept a lower percentage share of good quality surface water and do not switch over to using more groundwater.
- *Likely result:* No change in irrigation water supply conditions in downstream watercourse commands; continued increase in secondary salinization and deterioration in groundwater quality.

Head-end farmers already exploit locational advantage to appropriate as much surface water as they can in the periods of peak demand and they also have a high density of tubewells which are not used to full capacity. There is no particular reason why they should willingly agree to a reduction in their favorite irrigation water source and their profitable agricultural system. On the other hand, if it is assumed that head-end farmers respond by accepting such a management intervention; then:

- *Probable response:* Head-end farmers forego their locational advantage, accept less surface water and increase their groundwater pumping rates to those found in tail-end areas.
- *Likely result:* Cropping patterns in downstream watercourse commands change to ones more like those in distributary-head-reach areas as do the relative water supply conditions; processes of secondary salinization and groundwater quality deterioration continue at a slower rate downstream, but increase in upstream locations.

Shifting to greater groundwater use in areas where EC values are still relatively low, less than 1.2 dS/m, may appear intuitively attractive, but if the proportion of groundwater used here increases from 60 percent or 70 percent to the 85 percent currently found in tail-end areas, it is probable that soil and groundwater EC levels will also begin to rise in these locations.

Alternatively, in an intervention where more, higher quality surface water is made available through an intra-system or inter-system reallocation of supplies, the following sequence of events may occur:

- *Intervention:* Increase surface water supplies to an entire distributary command so that farmers in middle and tail reaches can get an increase over currently sanctioned allocations.
- *Probable response:* Farmers throughout the command attempt to increase summer cropping intensities and grow more rice by pumping more groundwater to match surface water quantities now available.
- *Likely result:* Farmers in head-end areas may attempt to capture still more water at the expense of middle and tail watercourses; there may be an amelioration of the rate of salinization in tail-end areas of favored distributary commands; canals that have "lost" fresh water will likely experience more rapid increases in salinity because of increased use of groundwater.

In some respects, this second option is a classic zero-sum game: every area that benefits by obtaining more surface water can only do so at the explicit expense of areas which will have less surface water. The benefits in the short run may look favorable, but the long-run implications still continue to be ominous.

Long-Term Options

However, on a long-term basis, none of the above scenarios may work. The central issue here is the ratio of surface water to groundwater in conjunctive use in irrigated agriculture identified in this research. On average, it is about 2:5 throughout the distributary command, resulting in an

average irrigation water EC of 1.4 dS/m. This value exceeds the current international FAO⁴⁰ based standard that sets the upper limit for "good" quality irrigation water at EC 0.7 dS/m; but it is within the safe upper limit of WAPDA's guidelines, based on 1954 standards.

To bring that average water quality condition down to 1.0 dS/m, still about 40 percent higher than the FAO maximum value, a canal water/tubewell water conjunctive use ratio of 3:4 would be required. Assuming no change in the total volume of irrigation water used in the command area, this means that the volume of canal water would have to be increased by more than 50 percent and the volume of pumped groundwater reduced by more than 20 percent *of current volumes*. The present physical condition of Punjab's distributary canals precludes any possibility of accommodating a 50+ percent increase in discharges without frequent, massive breaching, even assuming that enough farmers could be convinced to reduce groundwater pumping by the required amount which is no mean management feat.⁴¹

Increasing the volume of canal water would also require additional surface storage. Efforts over the past decade to construct new storage reservoirs, such as the Kalabagh Dam, have been deadlocked because of seemingly unresolvable differences between the provinces.

An alternative, and one that in reality is already occurring in parts of Punjab, is the reduction of the irrigated area. There is a trend towards a loss of tail-end land either through abandonment or reduced frequency of cultivation. From a technical and agronomic perspective it is probably rational to allow this to happen, and to concentrate higher quality water on a smaller area and allow these areas to prosper through adoption of better agricultural practices. Whether there is the political and social support to allow this to happen, of course, is another matter.

In short, there is no single, "magic bullet solution" in sight to the problem of sustaining a productive irrigated agriculture, which is posed by secondary salinization and groundwater quality in the current conjunctive-use environment of large, agriculturally important areas of Punjab. What is very clear, however, is that the present conditions in that environment are dynamic and that the direction of change is not encouraging.

RESEARCH ISSUES AND MANAGEMENT IMPLICATIONS

The research results discussed in this paper, which are necessarily based upon a limited sample and data from just 41 watercourse commands out of the more than 89,000 that exist nationwide, are probably not statistically significant. Nevertheless, the trends that have been identified are sufficiently consistent between spatially separate locales to provide grounds for genuine concern. These trends point to several important management and research issues in the area of conjunctive irrigation, certainly applicable to Punjab and perhaps to other areas in Pakistan.

Research Issues

Areas where further research is likely to produce results and insights that will be useful in developing suitable management responses and institutional changes include the following:

40 Food and Agriculture Organization of the United Nations.

41 Additions to full supply discharges have been simulated using a flow model, *IIMI Rajbah I*, for known distributary-channel physical conditions. The certain consequence of a 20 percent increase over present full supply levels is breaching at any of the innumerable locations in the upper half of the channel.

- Determining realistic critical limits for surface water/groundwater ratios at different water qualities for a range of physical environments of the Indus Basin. Field verification of those values is necessary, spatially and over time, as are the corresponding relative water supply targets. The relationship of the resulting parameters to values of current farmer irrigation water use over a similar environmental range will need to be considered in designing extension service interventions that facilitate necessary changes.
- Development of a model that is able to predict salinity changes over time in relation to different intensities of groundwater use for different surface water and groundwater qualities. Such a model is essential for decision support of aquifer management for long-term sustainability. It could help evaluate the impact of periodic, but not permanent, reallocations of water around the system to facilitate leaching for salinity management.
- The factors that affect farmer cropping choices in conjunctive-based irrigated agriculture need thorough analysis. In this paper, this has been done only in the context of water quality and location; other economic, social and physical factors may be important as well, and evaluation of perceptual variables would also be desirable. The application of geographical information systems (GIS) would be advantageous here because of indications of a close relationship between the cropping choice and the geographical location within the canal command.

Until some of these issues are explored further, it is hard to see how appropriate management actions can be taken.

Management Issues

From the perspective of managing conjunctive irrigation to mitigate those processes that may threaten the sustainability of Pakistan's irrigated agriculture, there are three primary needs to be addressed. They are understanding current trends in the conjunctive use of canal water and groundwater, organizing for changes in the management of government inputs into the sector, and policy review and planning. Each is briefly addressed below.

Understanding Current Trends in Conjunctive Use

IIMI's research has indicated that there are large gaps in the conventional understanding of conjunctive use in Pakistan. It is also clear that the national capacity to bridge these gaps is weak. A major reason for this is the virtual absence of any coordinated data collection program for relevant variables within national and/or provincial organizations. For example, consider the following types of essential data that are collected; the processes do not coincide geographically or temporally, nor have the resulting data ever been assembled into a single location in Pakistan.

- **Surface water data** is collected by the Irrigation Departments or by WAPDA's Watercourse Monitoring and Evaluation Directorate and Alluvial Channels Observation Project.
- **Public-tubewell data** is available with WAPDA's SCARP Monitoring Organization, the Irrigation Research Institute, and the tubewell operations units of the irrigation departments.

- **Cropping data** is collected through the Agricultural Census, the Irrigation Department's assessments for water charges, and the activities of the Agriculture Department's On-Farm Water Management Directorate.
- **Yield data** is collected by the Agriculture Department's Crop Reporting Service and through the Agricultural Census, but is not referenced to hydraulic location, only to civil divisions.
- **Private-tubewell data** remains largely outside the purview of any public agency, even though such wells now account for more than half of all irrigation water used in much of the Indus Basin.

Thus, while the Punjab Irrigation Department continues to perceive "the irrigation system" primarily as a canal system, while responsibility for public-sector groundwater operations remains organized and implemented essentially independent of surface-system operations, and while private-sector groundwater operations are completely unmonitored, it is not surprising that the threat to the sustainability of irrigated agriculture based upon present patterns of conjunctive use is largely unrecognized and little understood. When a national research institution, such as WAPDA's SCARP Monitoring Organization, restricts its monitoring and applied research activities to public-sector tubewell groundwater operations, independent of spatially coincident surface irrigation systems and private-sector groundwater development, while using water quality standards long out-of-date, it is unlikely that its work will have more than limited utility in defining the problem or in the development of solutions.

Clearly, arresting the processes of resource deterioration in the present conjunctive-use environment requires both provincial and national water and agricultural sector agencies and research institutions to recognize and respond to the present *realities* of Pakistan's irrigated agriculture with coordinated, cooperative and effective actions. The need is not new, of course, but in the context of increasing constraints on development resources and the very high rate of population growth in Asia, neither has it been more urgent.

Changes in Management of Government Inputs

A similar lack of overall coordination and effective collaboration occurs within the line agencies responsible for providing water and other services to farmers in areas of conjunctive use. The Irrigation Department persists despite its surface, tubewell and drainage divisions having completely uncoordinated boundaries; WAPDA's supply of electricity is unrelated to agricultural needs and its rural grids crosscut canal commands; divisional boundaries within Agriculture Departments rarely coincide with those of any of the hydrological units used in the Irrigation Departments. The On-Farm Water Management Directorate plans and implements its interventions in watercourse commands without knowledge of canal operations or of private tubewell development. Its sister organization, the Agriculture Extension Directorate, is ignored by all of the foregoing, perhaps because it remains incapable of effectively advising farmers on any important aspect of irrigated agriculture. So long as this situation prevails the odds that the changes, say, in water supply intended to alleviate the negative impacts of salinity, will be met with any improvement in overall conditions are very long.

Pakistan's public agencies and supporting research institutions must begin shedding this "historical baggage," reorganize internally and establish functional, working linkages with one

another. This seems an essential prerequisite for any effective use of better information and knowledge to design and implement appropriate, coordinated, management-focused responses to the problems of conjunctive use identified in this paper. Admittedly, how this will be achieved in the current environment of belief that change is impossible, a widespread lack of will among senior professional staff, increasingly frequent political interference, declining professional standards among junior professional staff, and a growing institutional malaise that borders on paralysis is by no means clear.

Policy Implications

Amelioration of the trend toward a declining sustainability of Pakistan's irrigated agriculture ultimately comes back to the policy environment in which other necessary actions will have to be taken. The cries for institution realignment and more performance-oriented management by government agencies at the field level have been heard before, sometimes for long periods, and yet no action has really been taken. Until there is a genuine commitment at the national level to implement policies and allocate resources that will positively stimulate these changes, it is unlikely that they will materialize.

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CHAPTER 7

Participatory Action Research in Irrigation Management: An Example from Kirindi Oya

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and
C.M. Wijayaratna***

INTRODUCTION⁴²

IN MANY DEVELOPING countries, there are few national research agencies that work on irrigation system management research. Existing irrigation research units generally focus on specific components of research such as hydraulic model testing, soil mechanics, soil-water-plant relationships, socioeconomic base-line studies, etc.

IIMI has been experimenting with various modes of collaboration with national research partners, including irrigation management agencies, in capacity creation, knowledge generation and utilization. Participatory action research (PAR) is a mode of collaborative research now being used by IIMI in Sri Lanka to work with national partners. Unlike many of the approaches taken elsewhere (Levine 1992), participatory action research is a full partnership with IIMI's collaborators.

Participatory action research in irrigation management is a mode of research in which the system management agencies, including farmers, become the implementors of the research program. The basic premise of participatory action research is that full involvement of the agency and the farmers can be an effective method for ensuring that their concerns are incorporated into innovations and that they understand, accept and transmit the research results. Participatory action research can be an efficient mechanism for developing coordination among various agencies and the farming community for research-based problem-solving; also it results in more cost-effective, economical and sustainable internalization of research innovations.

This paper defines participatory action research in irrigation management, then describes its use in the case of the Kirindi Oya Project in Sri Lanka, and finally turns to evaluating its strengths and weaknesses.

⁴² The authors wish to acknowledge the contribution of Dr. Douglas J. Merrey who, with Dr. R. Sakthivadivel, conceived of the use of participatory action research as the methodology for Phase 2 work at Kirindi Oya when he was Head of IIMI Sri Lanka Field Operations.

PARTICIPATORY ACTION RESEARCH (PAR) IN IRRIGATION MANAGEMENT

In conventional applied research in irrigation management, research activities are carried out by researchers. The agency personnel and farmers in the field are the "subjects" of the research. The ideas are supplied by the researchers, tested in the field, and then documented in reports so that the results can be disseminated for use by others. In "action research" and "on-farm research," research activities are carried out by the local personnel under the directions of the researchers who then write up the results for use by others. Neither of these approaches ensures that the results will be adopted. It is normally left to extension or similar personnel to try to get others to adopt the successful innovations.

Participatory action research (Whyte 1991) is a methodology for applied research which incorporates the agency personnel and farmers not as subjects but as partners in the research work. In irrigation management research, the research activities are intended to improve the performance of an irrigation system.

In a PAR activity in irrigation management:

- Researchers together with agency personnel and, if appropriate, farmers, jointly plan innovations to be tested in the project.
- The planned interventions are made by the agency personnel and farmers.
- Much of the data needed to monitor and evaluate the innovation is gathered by the agency personnel and farmers.
- Researchers document the process and provide feedback to the implementors to allow for midcourse corrections.

The basic premise is that system operators and farmers should be involved in planning and implementing innovations because their detailed knowledge of the irrigation system workings will make improvements in performance more likely. With the involvement of the system managers in planning innovations, the innovations will respond to felt needs and not simply to outsiders' (i.e., the researchers') ideas. Also, if the system operators and farmers take part in planning and implementing the innovations, they will have a commitment to see them work. Involvement in data gathering gives the implementors direct access to the data so that their contributions to analysis of the happenings is magnified.

The implementors get involved to benefit themselves, not simply to provide data for a researcher to write up. Therefore, it is important to see that the results of the innovation are beneficial. This means that a PAR activity must be a learning process in which changes are made to ensure success as various things are learned. Researchers are specialists in documentation and reporting of the processes and results of the experiments. Their work in documenting what happens is essential to provide feedback to the implementors. Documentation also provides for wider dissemination of the results.

In PAR, the agency personnel and farmers are actors in the research process, not the subjects of research. Besides being documenters, the researchers are not only catalysts who bring new ideas to the problems but who help train the others in those ideas. To make these roles work, all involved have to put a good deal of effort into planning, training, and coordinating field efforts; teamwork is of vital importance.

The process yields three types of results:

1. Improvements in system performance that are likely to be implementable because they have been carried out by regular working personnel.
2. Internalization of the innovations among the implementors, including understanding how and why they work.
3. Research reports to disseminate the results of the experiment to others who can make use of them.

Unlike a conventional research approach, PAR ensures that the results are adapted to and adopted in at least one system. In order for a PAR activity to be a success, it must have results visible not only to the researchers but also to the system operators and farmers who have taken part. The system improvements and internalization of the innovations are of equal or greater importance than the reports.

PARTICIPATORY ACTION RESEARCH AT KIRINDI OYA

Kirindi Oya is a major irrigation scheme in the southeast region of Sri Lanka. It is a new scheme; the main reservoir, Lunugamvehera Reservoir, was completed only in 1985. It incorporates a much older river diversion scheme called the Ellegala Irrigation System.

IIMI was invited by the Asian Development Bank, the main funding agency for work in the new portions of Kirindi Oya, to assist with improvements in the system by carrying out diagnostic studies. The Phase I study results were published in 1990 (IIMI 1990) and the study concluded that:

The irrigation water use efficiency of Kirindi Oya was low and there was great potential for saving water if proper management policies are adopted for main canal operations. Water use efficiency can be considerably improved through effective use of rainfall and drainage water, skillful planning of scheduling and use of effective monitoring and feedback mechanisms.

- There would be a great improvement in water use efficiency if flexible scheduling were adopted, especially during the land preparation period, to match more closely the water use pattern adopted by the farmers.
- The effectiveness of maintenance management was not up to standard to provide long-term sustainability of the system. It was necessary to work with the Irrigation Department to develop and implement a cost-effective maintenance management system applicable to Kirindi Oya and replicable in other systems as well.
- There was a need to establish a more effective framework for integrated management of the system and to monitor its effectiveness; strengthening of farmers' participation through a single Project Management Committee was important to achieve this end.
- In view of the scarce water resources and large area to be brought under irrigation, there was an urgent need to diversify crops to use the water resources more efficiently and to maximize farmers' production and income.

- The Phase I report proposed a series of innovations in (a) water resource management for long-term performance, (b) crop diversification and cropping patterns, (c) design-management and water management interactions, and (d) institutional strengthening.

High-level government officers selected a few important and implementable recommendations for field-testing through participatory action research at Kirindi Oya with funds provided by the Asian Development Bank. This work started in May 1991 and will be completed by September 1993. Three areas were chosen for research: main system management, tertiary system management, and a pilot program in other field crops (OFCs). The following key activities were selected (IIMI 1991a):

1. Improvement of main system management through development and implementation of crop planning and seasonal water allocation plans, through more efficient main canal operation, through water balance studies of the Ellegala Irrigation System, and through maintenance management studies. Part of this work, the development of a computer-based canal management system, is being funded separately by the Government of France (Baume et al. 1993).
2. Improvement of tertiary system management through strengthening of farmer organizations, better tertiary maintenance management, improved seasonal planning, coordinated acquisition of agricultural inputs, and improved operations in field channels and distributary channels during the land preparation and crop growth periods.
3. Pilot-testing of water management methods for diversified mixed crops in a pilot area of 240 hectares. This effort included addressing the economic dimensions (marketing, labor, prices and profitability) as well as water management issues. Research activities included documenting and evaluating seasonal planning, documenting and evaluating different land preparation methods, documenting and evaluating irrigation scheduling, water distribution and water use for OFCs, and evaluating the economic performance of different OFCs.

IMPLEMENTATION OF PARTICIPATORY ACTION RESEARCH AT KIRINDI OYA

The distinguishing characteristic of PAR is that the actors "on the spot" take part in research as well as their everyday activities. The key concern of the authors was to ensure their full participation in the planning and conduct of the research.

The problem was complicated by the fact that the recommendations to be implemented through PAR involved several different government agencies, including the Irrigation Department (ID), the Irrigation Management Division (IMD), the Department of Agriculture (DOA), and the Land Commissioner's Department (LCD).

The basic strategy to get participation was through the creation of committees to oversee the various research components. Each committee was chaired by a local officer and included personnel from the involved departments together with IIMI researchers. IIMI placed an interdisciplinary team of four researchers in Kirindi Oya to assist with the planning and implementation and to document the process and results.

The steps for implementation of PAR in Kirindi Oya were defined as follows:

1. Establishing coordinating and implementing committees.
2. Preparing an inception report with the participation of the agency personnel and farmers.
3. Organizing planning workshops and preparing action plans for each activity.
4. Training implementing-agency personnel and farmers.
5. Implementing the action plans in selected areas.
6. Documenting lessons learned.
7. Extending the successful approaches to the whole scheme.
8. Documenting the participatory action research process and its impact on irrigation performance and crop diversification.
9. Preparing reports and training modules for replication at other schemes.

The research began at Kirindi Oya in May 1991. The progress of each of the steps is briefly described below (IIMI 1991b, IIMI 1992).

Committees and inception report. The first two steps were taken very soon after work began. First, IIMI researchers prepared a Draft Inception Report. Second, IIMI researchers together with agency personnel constituted the three substudy committees to guide implementation of each of the three components. In addition, an overall Study Coordinating Committee and a Study Advisory Committee were established to oversee the work.

The Draft Inception Report was discussed with agency personnel in a series of scheme-level meetings. The activities for each component were discussed with the respective substudy committee. These together with other meetings with both agency officers and farmers helped IIMI researchers to refine the Inception Report. Adoption of this procedure helped make the key officials involved in each component activity fully aware of the contemplated work.

Planning workshops. The Inception Report was finalized (IIMI 1991a) in a workshop held in June 1991. The workshop brought together field-level officials, the heads of implementing agencies, policymakers, donor agency personnel and IIMI researchers for in-depth discussions.

Based on a suggestion from the Inception Report Workshop, a second workshop was conducted in early August 1991 at which the implementing officers and IIMI researchers prepared detailed action plans. This workshop concluded that there was a need for training programs for the field-level officials who would implement the research activities. In addition, this workshop emphasized the need to have periodic discussion at different committee levels so that problems that can be solved at that level can be attended to by the respective committee and only those that cannot be solved will be taken to the next higher-level committee.

The participatory planning process resulted in the rejection of most of the recommendations made in the Phase I study (IIMI 1990) as not implementable. The components outlined above were selected and modified from a much longer list of items identified in Phase I.

Training. In view of these outcomes, a very high priority was given to field-level training and workshops. A list of workshop and training activities up to the end of October 1991 is given in Table 7.1.

Table 7.1. Progress of the workshops and training programs.

Name	Date	Venue	No. of participants	Purpose	Agencies
1. Irrigation and Crop Diversification, Phase II (English)	10-11 June 1991	Peacock Beach Hotel, Hambantota	58	To discuss Inception Report.	ADB, MEA, IMD, LCD, DOA, Ministry and IIMI
2. Planning Workshops	5 Aug. 1991	DTC, Weerawila	45	To plan and create awareness of the program.	ID, IMD, LCD, DOA, DAS and IIMI
a) Kirindi Oya (Sinhala)					
b) Walawe (Sinhala)	6 Sept. 1991	Centauria Hotel Embilipitiya	42	- do -	MEA, IMD and IIMI
3. Training for officers (Sinhala)	17 Aug. 1991	DTC, Weerawila	42	To discuss their involvement and contribution.	ID, LCD, IMD, DOA and IIMI
a) Awareness training for field-level staff (Kirindi Oya)					
b) Clerical Staff	5 Sept. 1991	MEA Auditorium, Colombo	18	To identify constraints and how to overcome them.	MEA and IIMI
4. Training for farmers (Sinhala)	16-19 Sept. 1991	MEA Auditorium, Colombo	80	To motivate and to internalize FC groups.	MEA and IIMI
a) One-Day Farmer Motivation Program - 4 groups (Walawe)					
b) Two-Day training for MKD & FC leaders	6-7 Sept. 1991	- do -	32	To provide knowledge in managing DCO.	MEA and IIMI
c) Training for FRs of DCs (Kirindi Oya)	29 Aug. 1991	DC, Weerawila	11	- do -	ID, IMD and IIMI
d) Training on water-sharing	3, 15, Sept., 2 Oct. 1991	Field	71		IIMI
e) DC meeting on research awareness for FRs (Kirindi Oya)	20 Aug. 1991	Field	12	Research orientation	IMD, ID and IIMI
f) Nursery Management (Kirindi Oya)	7 July 1991	Hamlet	30	Education on nursery management	DOA, IMD and IIMI
h) Land preparation (Kirindi Oya)	17, 18 Sept. 1991	- do -	30	Water sharing	- do -
i) Field trips (Kirindi Oya)	3, 17, 24 Aug. 1991	Field	30	OFC cultivation	DOA, IMD and IIMI
5. Research methodology workshop	4 Oct. 1991	SLFO, Colombo	12	Research methodology	IIMI

Notes:

ADB = Asian Development Bank

LCD = Land Commissioner's Department

DTC = District Training Centre

DC = Distributary Canal

FR = Farmer Representative

MEA = Mahaweli Economic Authority

DOA = Department of Agriculture

ID = Irrigation Department

MKD = Moraketiya Distributary

SLFO = Sri Lanka Field Operations

IMD = Irrigation Management Division

Ministry = Ministry of Lands, Irrigation and

Mahaweli Development

FC = Field channel

Implementing the action plans in selected areas. The workshops concluded that the proposed innovations should be tried first in selected areas (distributary channels) before being extended to the whole of the Kirindi Oya Scheme. Since the research project started in May 1991, the yala 1991 season (May–September) was used for planning, training of field-level officials and farmers, and collection of additional baseline data (IIMI 1991b). Implementation of actions started in the maha 1991/1992 season (October–March) in selected areas. In maha, Irrigation Department officers put to use for the first time new techniques for main-canal management, undertook data collection for the water balance study of Ellegala Irrigation System, and used new techniques for the planning of maintenance activities. Farmers worked with personnel from several agencies in using new techniques for clearing channels before the season, in using new water distribution patterns to solve tail-end problems, and in planting crops other than rice under irrigation. Aspects of this work continued through yala 1992 (IIMI 1992).

Extension to the whole scheme. During maha 1992/1993, some of these activities were being extended to the whole of the scheme, including aspects of the new main system planning and management systems, maintenance management systems, tertiary channel management planning, and OFC activities developed during the preceding two seasons.

Documenting lessons learned. IIMI researchers have kept track of the progress of each activity and of the lessons being learned. Results were reported through detailed seasonal reports (IIMI 1991b, IIMI 1992). To supplement the data being collected by agency personnel, researchers used surveys and independent monitoring of selected channel flows. Daily interaction between IIMI researchers and farmers and agency officers provided much of the information. Through both formal and informal means, the researchers helped to keep the various participants in the project aware of what is happening. Through the substudy committees adjustments were made to plans regularly to accommodate lessons learned.

Analysis of impact and reports for replication at other schemes. These steps will be taken in the future by the IIMI researchers in cooperation with the implementors.

IMMEDIATE RESULTS

Participatory action research (PAR) at Kirindi Oya has had some immediate results, particularly results that have led to improved coordination and the general adoption of a system-level consciousness of problems and constraints by agency officers and farmers. Some of the most important immediate results include the following.

Coordination among the Implementing Agencies

One of the biggest changes introduced by PAR is close coordination and understanding among the various implementing agencies (Irrigation Department, Irrigation Management Division, Department of Agriculture, Land Commissioner's Department and farmer organizations) in planning and implementing the action-research program. The increased coordination and understanding stem from the series of workshops and training sessions organized for the research and from the committees created to oversee the work.

Establishing a Unified Project Management Committee

Prior to the start of this research, two Project Management Committees — one for the new settlement area and the other for the old Ellegala Irrigation System — functioned side by side. As a result, there was little coordination in seasonal crop planning, water allocation, and operation and maintenance (O&M) activities. Also, different procedures were adopted for establishing and strengthening farmer organizations in the two areas. The establishment of a single Project Management Committee in May 1991 for the whole Kirindi Oya Scheme has allowed the joint discussion of seasonal crop planning and water allocation among the farmer representatives of the separate subsystems. This has done much to promote a system-wide view of problems and water allocations among both farmers and agency officers.

Organizational Changes in the Irrigation Department

Prior to March 1992, one irrigation engineer looked after the construction, operation and maintenance of the old Ellegala Irrigation System while the newly developed areas were under the charge of two irrigation engineers, one each for the Right Bank Main Canal and Left Bank Main Canal. This division of responsibilities created problems because the irrigation officers and lower-level functionaries felt compelled to espouse the interests of the farmer organizations in their respective areas.

Several features of the PAR project made these problems apparent to high-level Irrigation Department officers. First, sessions of the single Project Management Committee made it possible to give airing to the different interests of the various irrigation engineers. Second, the increased attention given to Kirindi Oya by officers through the research committees made happenings more visible. Third, the maintenance management studies carried out under the project made public the very high overhead costs of maintaining separate offices for these subsystems.

In March 1992, the Irrigation Department merged the old Ellegala Irrigation System with the Left Bank Main Canal under one irrigation engineer. The irrigation engineer in charge of the new division can now coordinate activities of both new and old areas to solve the water problems in a more realistic way. This merger has not only helped to improve the water allocation and operational problems but has also reduced O&M overhead costs.

Main System Management

Simulation modeling of the Right Bank Main Canal and related work under the French Project (Baume et al. 1993) have provided a methodology for canal operation monitoring and feedback that was implemented during maha 1991/1992 by the Irrigation Department. As a result of the implementation of the monitoring and feedback system, system managers are now in a position to know what is actually happening in the system under their control. The procedure used prior to the implementation of this system was to respond to farmers' complaints by making field visits. Now the system manager is in a position to know how the canal is functioning with a far smaller number of field visits. He is also in a position to give the canal operators clear instructions based on the data from the field.

Interviews with farmers reveal that water problems were reduced considerably during maha 1991/1992. The monitoring and feedback system has also helped the canal operators to perform

their duties systematically based on target discharge rather than on an ad-hoc basis by responding solely to farmers' requests.

Water Balance Study of the Ellegala Irrigation System

The Ellegala Irrigation System with its five interconnected tanks receives water from the Lunugamvehera Reservoir through a feeder canal from the Left Bank Main Canal. In addition, these tanks get rainfall runoff from their own catchments as well as drainage water originating from the new irrigated area. The releases from Lunugamvehera Reservoir to Ellegala vary from season to season depending on a large number of factors including the rainfall in the command area and the extent of new irrigated area.

Prior to this research, there were no reliable measurements of water releases to Ellegala and nobody knew how to calculate the amount of water from Lunugamvehera Reservoir needed by Ellegala. Without knowing this requirement, it is extremely difficult to allocate water to the new area, especially when it is a dry year. Because of the inadequate data, water releases from Lunugamvehera Reservoir to Ellegala were made on an ad-hoc basis. It was often observed that while the new system was in dire need of water, the tanks in Ellegala were spilling; this was the case in maha 1991/1992.

The flow measurement and water balance program initiated under PAR has provided limited but reliable flow data which allow the determination of the amount of water originating from the catchment rainfall and drainage as well as that released from the Lunugamvehera Reservoir. In addition, it has also provided information on the water released from the different Ellegala tanks during maha 1991/1992.

This has truly been a joint effort. The data collection plans were jointly designed by IIMI researchers and Irrigation Department officers, the data was collected by Irrigation Department employees, the computer model for data analysis was developed by an Irrigation Department engineer, and the actual data analysis and write-up done jointly by Irrigation Department officers and IIMI researchers.

Irrigation Department officers and IIMI researchers have used this information to develop a new release pattern from Lunugamvehera to satisfy the water requirement of the Ellegala Irrigation System as well as to make seasonal cultivation plans for the new system based on the expected inflow into the Lunugamvehera Reservoir.

Maintenance Management

The new maintenance management procedure developed and implemented at Kirindi Oya is based on diagnostic walk-throughs by agency officials and farmer representatives. Work is largely implemented using farmer contributions of labor to supplement resources provided by the government.

In maha 1991/1992, the preparation of work plans for one of the tanks in the Ellegala Irrigation System was done in a satisfactory manner using this approach and implementation during the closed season was successful. Preparation of work estimates on the basis of actual needs has been well-accepted by the agencies and farmers. The maintenance procedure and methods developed under this research appear to be implementable within the current government frameworks.

Table 7.2: Overall system performance.

Year	Season	Area cultivated (ha)							Water use			Rainfall (mm)
		RB Tr. 1 2&5	RB Tr. 6&7	LB Tr. 1&2	LB Tr. 3	ES	B'grains	Total	Total new area	New area (h)	Old area (h)	
1987	Yala	0	0	0		4,000	0	4,000	0			
1987/88	Maha	800	1,900	1,600		4,000	650	8,950	4,300	7.8	3.8	
1988	Yala	800	0	1,600		4,000	650	7,050	2,400	7.4	1.5	442
1988/89	Maha	800	1,900	1,600		4,000	650	8,950	4,300	9.5	1.4	720
1989	Yala	0	1,900	0		4,000	0	5,900	1,900	10.0	2.7	325
1989/90	Maha	800	0	1,600		4,000	0	6,400	2,400	9.7	2.5	370
1990	Yala	50*	0	2,400		0	650	4,900	250	16.0	5.1	351
1990/91	Maha	800	1,900	1,600	590*	4,000	650	9,540	4,890	8.6	2.1	780
1991	Yala	0	200*	0	150*	4,000	650	5,000	350	9.4	1.5	366
1991/92	Maha	800	1,900	1,600	740	4,000	650	9,810	5,160	6.6	1.2	661

Pilot OFC Cultivation

Pilot OFC cultivation in Left Bank Tract 3 during maha 1991/1992 demonstrated clearly the feasibility of raising OFCs in the maha season in well-drained soils. The experiment also provided information on the timing of OFC cultivation, land preparation requirements, drainage requirements and irrigation scheduling requirements for maximum production. The experiment is being repeated during maha 1992/1993. Meanwhile, the lessons learned from the experiment are being replicated in other tracts of the new area.

SYSTEM PERFORMANCE IMPROVEMENTS, MAHA, 1991/1992

Results from maha 1991/92 are presented to illustrate the outcome of the participatory action research. Three areas are discussed:

- Overall water use performance of the Kirindi Oya System.
- Main-canal operation performance.
- Tertiary system performance.

Overall System Performance

Overall system water use in Kirindi Oya System from yala 1987 through maha 1991/1992 is presented in Table 7.2. This Table brings out a number of interesting factors:

- The first water releases for the Kirindi Oya System were in yala 1986. Maha 1991/1992 was the first season in which all the area developed under the Kirindi Oya System was brought under cultivation.
- Water use for both the old and the new areas was the lowest during maha 1991/1992. There is a water saving of 2 acre-feet/acre from the previous maha season although the rainfall then was higher by about 120 mm.

As the total area of irrigation increases, water use generally decreases, thus partially explaining the improvements in maha 1991/1992. However, if one compares water use in maha 1991/1992 in the old Ellegala Irrigation System with that in Ellegala in maha 1990/1991, it is seen that there has been a dramatic decrease in the water supplied from Lunugamvehera Reservoir to the old Ellegala Irrigation System, although the rainfall has not been very different. This indicates that there has been an overall improvement in the operation of the Kirindi Oya System. This improvement is due in part to better understanding and coordination among the different line agencies and in part to the improved management performance by the Irrigation Department.

Main-Canal Operation Performance

In maha 1991/1992, the Right Bank Main Canal (RBMC) was selected as the pilot area for improvement of canal operations. The tract-wise performance of the RBMC is presented in Table 7.3. The average water use is about 6.3 acre-feet/acre against an overall water use of 6.6 acre-feet/acre for the Right Bank Main Canal and Left Bank Main Canal together. One of the main reasons for the higher efficiency of the RBMC was efficient operation of the main canal for economical use of the canal water.

Table 7.3. Tract-wise water use for RBMC, maha 1991/1992.

Tract No.	Area (ha)	Water supplied from canal (acre-feet/acre)	Rainfall contribution (acre-feet/acre)	Overall water use including rainfall (acre-feet/acre)
1	800	5.58	2.25	7.83
2	900	7.64	0.75	8.39
5	1,000	5.86	—	5.86
6 and 7	740	5.97	2.13	8.10

Table 7.3 shows that Tract 2 used the highest amount of canal water while Tract 5 used the least. In Tract 5, irrigation was started at the beginning of January instead of early November as in Tract 2. As a general rule, if irrigation is started very late in the maha season, water consumption is reduced considerably because rainfall reduces land-soaking and land-preparation requirements. Also, Tract 5 received a considerable amount of seepage water from the main canal as well as drainage water from Tracts 2, 6 and 7. Because of the dwindling storage in Lunugamvehera Reservoir, the Irrigation Department was also extremely careful in its supply of water to Tract 5. On the other hand, Tract 2, because of its very heavy canal losses, used the highest amount of canal water; also the rainfall contribution to this tract during crop growth season was much less than that to Tracts 1, 6 and 7.

An important result of this analysis is that the Irrigation Department officers who took part in the research by collecting and helping with the analysis of the data, now have a much better understanding of the problems of irrigating from the RBMC. They now have the ability to respond to the problems in a coordinated way that will serve all of the areas.

Tertiary System Performance

As shown in Table 7.4, the tertiary system management research component resulted in considerable saving of water. Table 7.4 indicates that the water used for land preparation on the pilot channel (Sub 1, Distributary Channel 5 in Right Bank Tract 2) was 577 mm in maha 1991/1992 against 840 mm reported for Distributary Channel 2 in RB Tract 5 in maha 1989/1990 (IIMI 1990). During the crop growth period, the Irrigation Department (ID) could not implement a rotation within the distributary channels as planned. Instead the ID responded to rainfall by closing the canal on rainy days. As a rough rule, they closed the canal for one day for every 30 mm of rainfall.

Table 7.4. Tertiary system management, maha 1991/1992.*

Total water use for land preparation period								
Date	Week	RF	ET	SUB	FC 51	FC 48	FC 49	FC 50
15-Sep.	1	0.00	55.40	58.40	99.11	116.06	25.40	41.04
22-Sep.	2	3.20	56.20	115.80	126.16	109.96	88.73	132.96
29-Sep.	3	18.10	33.10	108.36	133.67	137.06	87.12	106.69
06-Oct.	4	4.10	45.40	111.85	141.43	116.12	84.71	106.74
13-Oct.	5	59.40	23.30	70.48	77.27	43.57	54.13	79.27
20-Oct.	6	40.00	35.00	72.38	110.81	79.44	62.01	58.58
27-Oct.	7	103.10	8.30	39.54	47.51	42.48	37.11	35.31
Duty (mm)		227.90	256.70	576.81	735.96	644.68	439.21	560.60
Duty (acre-feet)		0.75	0.84	1.89	2.42	2.12	1.44	1.84
Total water use for crop growth period								
03-Nov.	8	43.70	15.10	80.54	91.21	98.81	79.10	59.41
10-Nov.	9	126.00	21.80	37.16	43.67	30.07	35.98	43.33
17-Nov.	10	27.40	18.80	34.61	37.89	13.10	25.53	37.86
24-Nov.	11	13.80	23.90	97.72	101.55	96.00	73.38	101.37
01-Dec.	12	0	36.10	97.77	127.09	60.92	81.29	90.50
08-Dec.	13	62.60	8.50	56.10	71.95	36.29	52.08	45.94
15-Dec.	14	146.30	18.10	4.41	6.05	6.60	4.35	1.87
22-Dec.	15	9.60	23.60	61.69	84.29	97.51	54.56	30.39
29-Dec.	16	12.30	23.30	89.11	97.75	62.53	78.23	91.64
05-Jan.	17	3.00	28.00	69.94	81.43	89.87	56.78	52.64
12-Jan.	18	2.10	24.00	53.10	64.57	67.31	43.68	36.00
19-Jan.	19	0	22.20	29.34	27.84	46.52	20.74	41.98
Duty (mm)		446.80	263.40	710.48	835.29	705.52	605.70	632.94
Duty (acre-feet)		1.47	0.86	2.33	2.74	2.32	1.99	2.08
Total for maha season								
Duty (mm)		674.70	520.10	1,287.29	1,571.25	1,350.20	1,044.91	1,193.53
Duty (acre-feet)		2.21	1.71	4.22	5.16	4.43	3.43	3.92

*The Irrigation Department believes that these figures seem "to be rather high" and that may be due to a measuring or calibration inaccuracy.

The low mean Relative Water Supply (RWS) and Cumulative Relative Water Supply ratios shown in Figures 7.1 and 7.2 indicate that the ID and the farmers succeeded in decreasing the use of canal water for land preparation but not during the crop growth period. However, a mean RWS value of 1.2 to 1.5 is a good achievement compared to a value of 1.5 to 2.0 in the previous seasons. A better water distribution plan during land preparation period coupled with better coordination among the implementing agencies and the farmer organizations appear to be the major reason for the improved performance of the tertiary system.

Figure 7.1. Cumulative RWS for field canals.

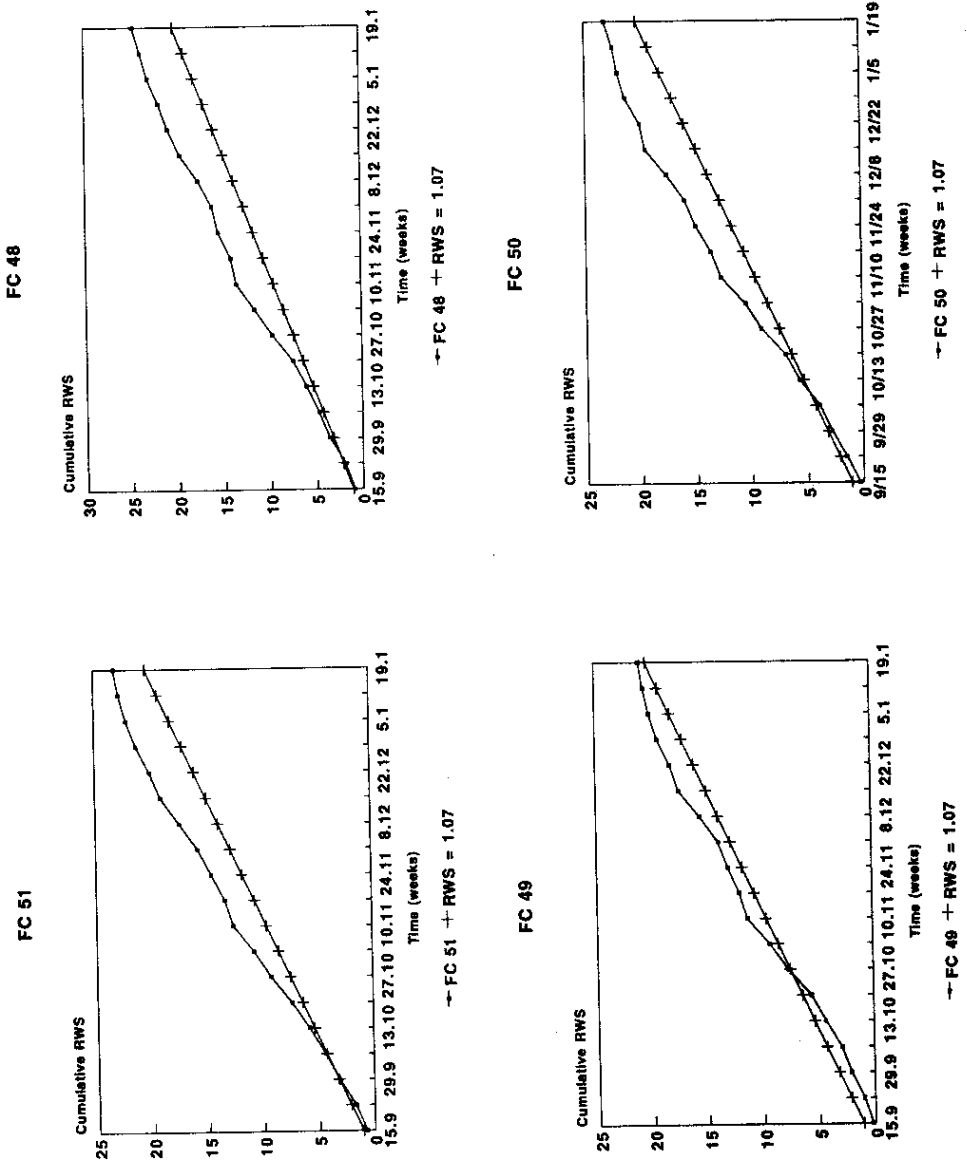
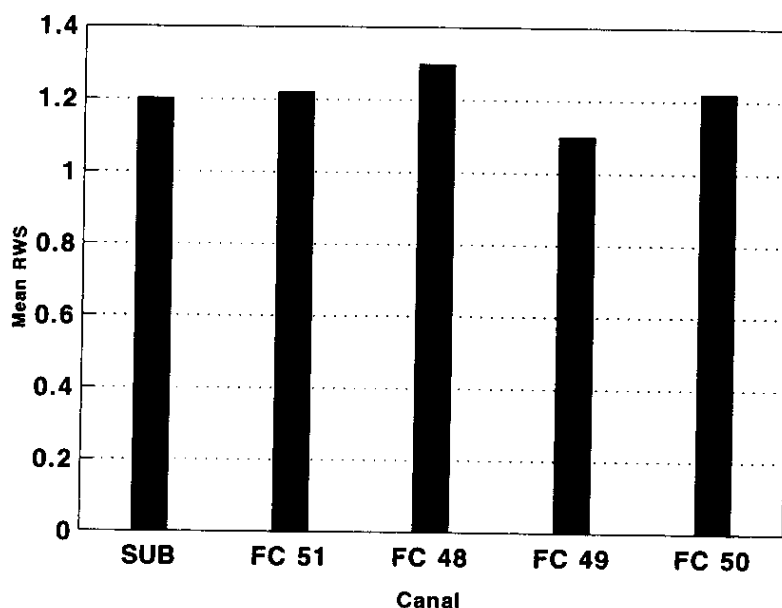


Figure 7.2. Mean relative water supply, RB Tract-01, maha 1991/92.



CONSTRAINTS ON PARTICIPATORY ACTION RESEARCH IN KIRINDI OYA

Research at Kirindi Oya has not progressed totally smoothly. There remain major difficulties in achieving some of the objectives of the research. Two of these difficulties are those with the PAR process itself.

Getting and Maintaining Participation

Maintaining the wholehearted participation of the agency officers and farmers is essential. They must feel that they "own" the project. Three factors have made it difficult to get and maintain sufficient participation:

- The roles and tasks of implementing officers.
- The commitment and leadership of the implementing agencies.
- Economic conditions of new settlement area farmers.

Roles and tasks of implementing officers. Participation in research activities requires a considerable amount of time and effort on the part of the implementing agency officers. Unfortunately, their roles and functions have not been redefined. The research activities are extra

work rather than activities that fit into their normal duties. The workload of many officers has been considerably increased by the need to coordinate, implement and monitor the program. While some of the officers are quite willing to put in the extra effort, others feel that the required effort is excessive. Also, some feel that there is no proper recognition and incentive for the extra work. If these research activities are to be internalized and sustained, there is a clear need to redefine the roles and functions of the implementing officials to build in an incentive system for better performance.

Commitment and leadership of implementing agencies. Four government agencies plus a number of farmer organizations are involved in implementing this research. The agencies at Kirindi Oya are headed by officers of more or less equal rank. A key requirement of these officers is their commitments to get the full participation of lower-level staff. Unfortunately, the local heads of departments vary considerably in their commitment to participation. The experience gained so far suggests that, at least in Sri Lanka, it would be more effective if there were a single manager at the project level who has the power and authority to coordinate the various line agencies, implement and monitor new activities such as the participatory action research and provide the necessary leadership.

Economic conditions of new settlement area farmers. Surveys conducted for the tertiary system management component show that at least 50 percent of the farmers in the new areas have serious economic problems. A great many have leased their lands to outsiders and others in their own hamlets. Many farmers have become wage laborers in their own leased out lands. A minority of the farmers are still entitled to bank loans; the rest are defaulters. The farmers complain that they are suffering primarily from water shortages which give poor yields and which limit the cropping seasons to an average of about one per year.

The farmers in the new areas are settlers brought from other areas. One result of the poverty is that only farmers without other resources live permanently in the new settlements; others live much of the time elsewhere where their income opportunities are greater. Since resident farmers can cultivate only one season per year, they depend more on wage labor and chena cultivation than on irrigated farming activities. Other farmers reside in their original villages outside the area and come to Kirindi Oya only when there is water for cultivation. Dual residence coupled with lessened dependence on irrigated agriculture has caused considerable problems in effectively organizing farmers for any purpose, including participatory action research. Basically, farmers are either not available to work with organizations or they have greater interest in other activities. As a consequence the farmer organizations are very weak.

Lack of Power to Make Needed Changes

Some of the management innovations needed require institutional changes and changes in operations and procedures of the agencies. Unfortunately, many of these changes are outside the authority of the local officers and require concurrence or action by superiors. However, as has been shown elsewhere, it is almost always far easier to demonstrate the value of management innovations than to get the necessary institutional changes made (Bandaragoda and Firdousi 1992). Interests in the status quo make institutional changes slow and difficult. This appears to be true for participatory action research in Kirindi Oya.

For example, research has clearly shown the value of the new monitoring systems in use on the Right Bank Main Canal. However, much of the essential data collection work is being carried

out by Irrigation Department officers as additional labor for which they are being rewarded with extra pay. This is not a sustainable situation. To get this work made part of their regular duties requires changes in the job definitions of these officers and a corresponding reduction in other duties. It also requires changes in evaluation of their performance by their superiors. None of this can be accomplished without the consent of their union and of the highest authorities in Colombo. Both of these have other concerns and interests to protect.

Probable Effects of Constraints

These two constraints affect both the conduct of the research project itself and the sustainability of the innovations:

1. First, without effective participation, many of the actors will not feel ownership of or commitment to the research activities thus making the activities themselves less likely to succeed. Without the power to make needed changes, some of the most valuable innovations cannot be tried. For both reasons, the research suffers limitations.
2. Second, without the understanding and internalization of the innovations brought about by full participation, the agency personnel and farmers are not as likely to continue the innovation following the end of the research. More importantly, without the institutional and procedural changes that reward maintenance of the innovations, it is quite likely that they will be abandoned once the researchers leave.

The second is the greater problem. Lack of participation can be and is occasionally remedied by increased participation by the researchers. For example, in the tertiary management component, one of the IIMI researchers was forced to provide help to a farmer organization when it became clear that the officers assigned to the duty would not be able to provide sufficient assistance. While the authors recognize involvement of the researchers in this type of action as a mistake, the limited time available for the research project sometimes forces such deviations. While involvement of the researchers helps with immediate implementation of the innovations being pilot-tested, it decreases the likelihood of their being sustained in the future.

THE VALUE OF PARTICIPATORY ACTION RESEARCH

In the Kirindi Oya System, participatory action research (PAR) has clearly demonstrated its ability to achieve significant improvements in system performance. As pointed out above, the constraints are most likely to affect the sustainability of the innovations being introduced. Although PAR is achieving some of the desired results in Kirindi Oya, there remain questions concerning its value as a research methodology. Some of these are considered here.

Is PAR a Research Method or a Development Method?

PAR clearly shares aspects of both research and development. As mentioned earlier, there are three expected outputs:

1. Improvements in system performance that are likely to be implementable because they have been carried out by regular working personnel.
2. Internalization of the innovations in the implementors, including understanding how and why they work.
3. Research reports to disseminate the results of the experiment to others who can make use of them.

The first two outputs serve development goals, only the third serves a research goal. Indeed, without the third, PAR is arguably a participatory development method rather than a research method. However, with the inclusion of data collection, reporting and analysis for a wider audience, PAR is not only a research method but is in fact the only method that can be used for many kinds of irrigation management research.

Most irrigation management research, by its very nature, must be carried out on live systems. Without the direct participation of the system managers or the farmers, the only way such research can be carried out is for the researchers to take over the system. In many instances of management research, participation of local personnel is limited to carrying out the orders of the researchers. Unfortunately, taking over the system means that many real world factors that affect the functioning of an innovation will be ignored.

Thus, if the goal of the research is to pilot-test an innovation in the real world, full participation of the local personnel, including their taking responsibility for both the planning and implementation of the research, is required. Only if local personnel can assist with planning and implementation will they be able to identify the relevant factors that have been missed by the researchers.

PAR as a Research Method: Rigor and Process Documentation

As a research method, PAR has the fundamental drawback that many variables cannot be controlled. Because the processes are modified during the work, a PAR activity is not a clean experiment. Results rarely include unambiguous confirmation or rejection of a hypothesis. Also, results are likely to be limited to the one system where the experiment is carried out.

In these circumstances, how can adequate rigor be guaranteed so that the results can be made useful to an audience of researchers? There is no simple solution and there is a current debate among researchers in organizational development about rigor within PAR (Whyte 1991).

If the process itself is documented so that both the idiosyncratic features of the local environment and of the process can be identified, general principles can be clearly separated from local circumstances. Such separation will allow the drawing of wider conclusions. Unfortunately, the authors cannot yet say that they are documenting the process in Kirindi Oya in sufficient depth, although they are making every effort to do so.

PAR as a Development Method: Sustainability and Support

One of the potential strengths of PAR as a development method is that, when properly done, it guarantees internalization of the successful innovations within the participants. Internalization, however, is not a guarantee of sustainability. As pointed out earlier, the sustainability of the

innovations is threatened by the lack of ability to control outside factors and by failures in getting the proper degree of participation.

How can the chances of making innovations introduced through PAR sustainable be increased? The authors suggest that PAR activities in irrigation systems should be coupled with development of a support institution, preferably within the agency most directly affected. The institution would not only be able to carry out PAR activities, including preparing and disseminating the lessons learned, but would be able to act as a lobby for the needed external changes.

In Sri Lanka, IIMI is now engaged in working with the Irrigation Department to develop the new Irrigation Research Management Unit (IRMU) into just such a support entity. It is expected that, in the future, the IRMU will carry out diagnostic activities on irrigation systems, and then mount PAR activities to improve system performance. By analyzing and collating the results of these activities, IRMU will be able to identify organizational and procedural reform needs requiring action at levels above that of the individual scheme. IRMU can then present well-documented proposals to the appropriate officials in order to effect the needed changes.

Finally, the authors suggest that this strategy of coupling PAR and a support unit is likely to be an effective means for institutional strengthening and for introducing management innovations in many developing countries.

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CHAPTER 8

Use of a Simulation Model as Part of a Management Information System to Improve the Operations on an Irrigation Canal in Southern Sri Lanka⁴³

Jacques Rey

INTRODUCTION

SINCE ITS INCEPTION, the International Irrigation Management Institute (IIMI) has been studying the management of main canal systems. Several studies showed that due to the complexity of their hydraulic behavior these systems are often difficult to control and function under unsteady flow conditions which can prevent the managers from achieving their water delivery targets. Seeking innovative ways of tackling these difficulties, IIMI embarked on a research project to investigate the potential for using new decision-support tools like flow simulation models.

With a view to improving the management of manually operated main canals through the routine use of such tools, IIMI concentrated its efforts on a pilot study in Southern Sri Lanka in the Kirindi Oya Scheme (Figure 8.1).

It soon became clear while designing the framework of this study that the introduction of a simulation tool in this operational environment had important implications in terms of communication needs within the system and availability of real time monitoring data.

A possible approach seemed to be to address the problem as a rationalization of the canal management through the development of a simple Management Information System integrating the simulation tool for specific processing.

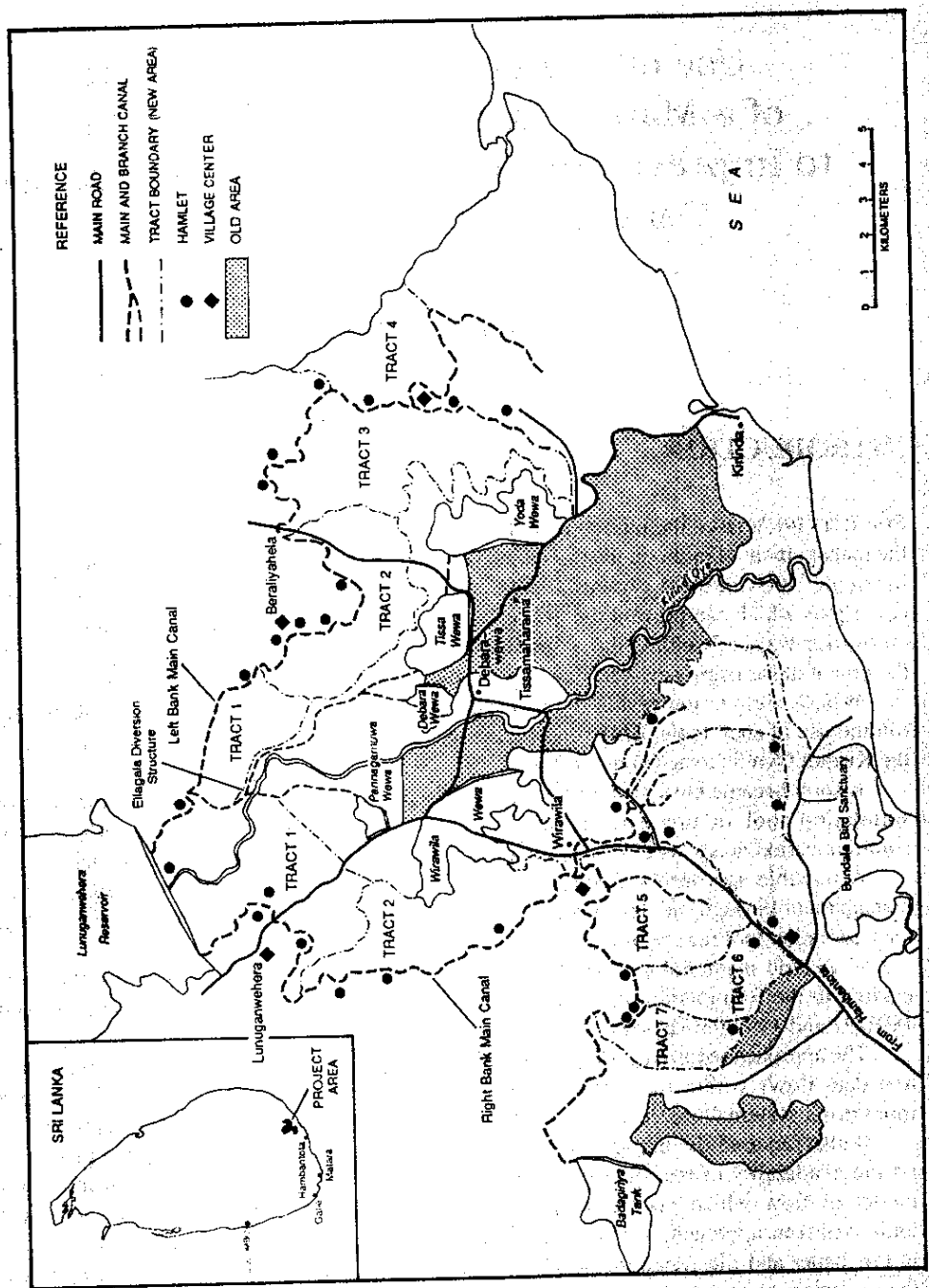
A generic methodology based on system analysis was adopted to diagnose the problems, leading to the formulation of an action-plan to be implemented over two seasons of irrigation: 1991/92 and 1992/93 wet seasons.

The approach required putting some effort into understanding and controlling the information and data flows within the system. This was addressed by the introduction of a rationalized monitoring system (June/July 1991) and the storage of data in a computerized database.

It also required the introduction of some innovations in the decision-making process, based on the availability of real time information and, progressively, the assistance of the simulation model of flow which permits a better understanding of hydraulic conditions. The methods underlying this approach, which will be field-tested during the next irrigation season are presented in this paper and illustrated through the discussion of a particular operational problem faced by the irrigation manager.

⁴³ This paper has benefitted from the constructive comments of Mr. Sarath Wijesekera, Resident Engineer, Right Bank, Kirindi Oya Project, the Irrigation Department of Sri Lanka and Mr. Manju Hemakumara, Research Officer, IIMI.

Figure 8.1. Kirindi Oya Irrigation and Settlement Project.



OPERATIONAL CHALLENGES

The Physical System

The Kirindi Oya Right Bank Main Canal (RBMC) is a 30-km long earthen canal. Its design discharge is about $10 \text{ m}^3/\text{s}$ at the head; its bed width varies from 10 m to 3 m and its average slope is 35 cm per km. The water levels are maintained all along the canal by means of 18 gated cross structures called gated regulators (GR). Water is issued to the secondary network through 42 gated offtake structures (see Figure 8.2). The command area of the RBMC is divided into 4 subdivisions called tracts; its whole extent is in the range of 3,300 hectares (ha), each tract having an area varying from 500 to 1,000 hectares. The water storage at the head is ensured by the Lunugamvehera Reservoir with a capacity of 200 MCM.⁴⁴

The reservoir supplies water to another main canal (left bank) bringing the total command area of the irrigation scheme to approximately 10,000 ha. A severe hydrological deficit in the area makes it difficult for the irrigation agency in charge of the scheme to supply water for ensuring a cropping intensity higher than 100 percent. Even if during the wet season or *maha* (October to March), most of the command area is under cultivation, it is rather difficult to ensure adequate deliveries during the dry season or *yala* (April to August). Thus the operational context of the scheme is one of water scarcity.

The Managerial Context

The operational management of the scheme is in the hands of the Irrigation Department of Sri Lanka. As given in the organizational setup presented in Figure 8.3, the overall coordination of activities at the main-canal level is performed by a Resident Engineer. His main objective, as far as the water deliveries are concerned, is to ensure that the water stored in the reservoir is used in an efficient way. This implies a careful planning of water releases from the reservoir and a good supervision of the water delivery process all along the conveyance network (main canal, secondary canals, tertiary canals) up to farmers' fields. He is assisted in his tasks by an additional engineer and technical assistants who transmit instructions to and guide the field staff units. A field staff unit, in each tract, comprises one work supervisor and three to four gate keepers.

Until recently the management practices were characterized by a relatively high degree of decentralization, most operations (manual) at the structures being implemented locally according to local objectives (targeted water levels). Overall coordination and inter-tract communication were sought only in cases of severe perturbations along the canal.

This system is actually functioning reasonably well under stabilized hydraulic conditions (for example, phases of constant water release at the head sluice and fixed water delivery pattern at the offtakes in the case of rice cultivation) but does not allow a proper control of water deliveries by the manager during more difficult phases of management such as changes in head sluice discharge, starting of water issues in one stretch of the canal, rainfall events or intermittent irrigation.

⁴⁴ Million cubic meters.

Figure 8.2. Issue tree of the Kirindi Oya Right Bank Main Canal.

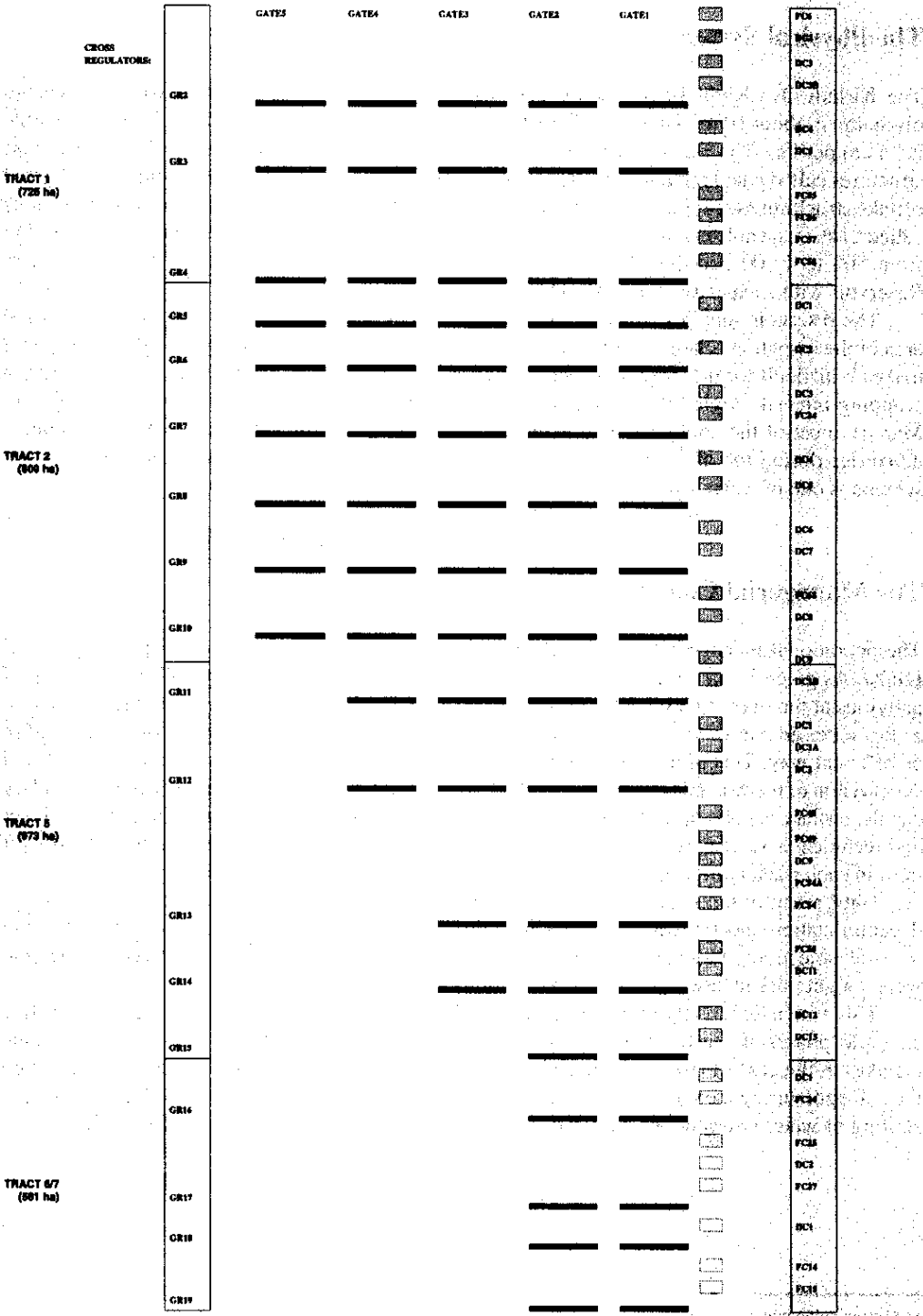
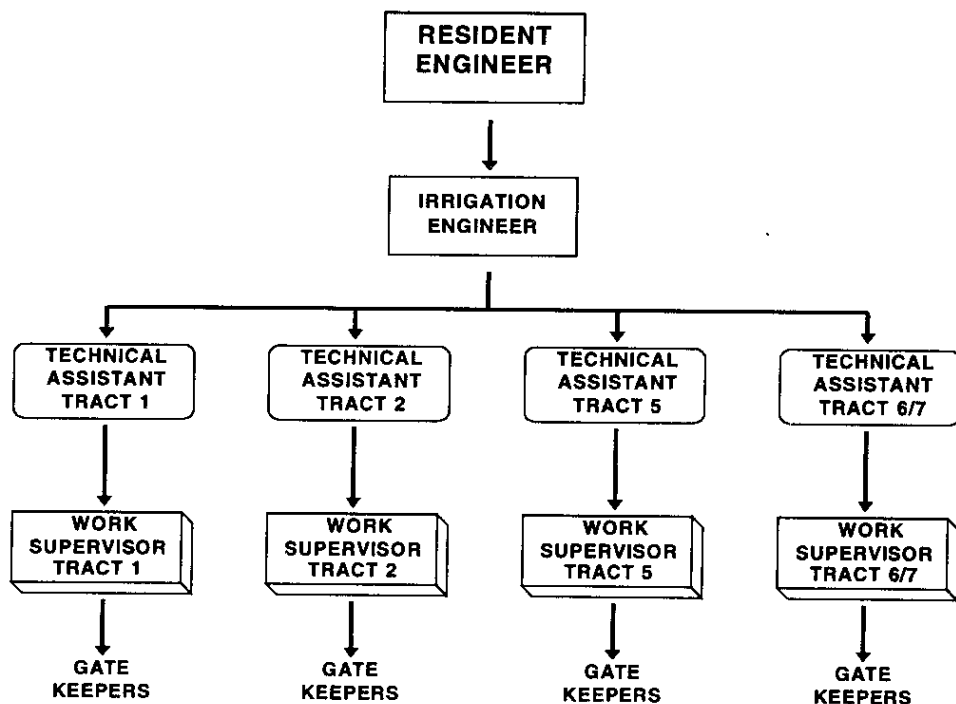


Figure 8.3. Organizational setup, Resident Office, Kirindi Oya Right Bank Main Canal.



Operational Difficulties

This type of operational conditions (intermittent irrigation) has become a challenging concern in Kirindi Oya.

As a tentative response to the water-scarce conditions of the scheme, diversified cropping patterns have been promoted in order to progressively replace rice cultivations with less-water-demanding crops on the well-drained soils of the command area. The water delivery patterns required for these crops imply more sophisticated operational plans (see example in "Illustration of the Decision-Support Approach," page 217).

The generic research question, therefore, to be addressed by IIMI was: How can the planning capabilities of the irrigation canal manager be strengthened in order to ensure a good responsiveness to new and more complex operational scenarios?

The first important requirement identified was to get a better understanding of the hydraulic functioning of the canal. A proper tool to address this issue appeared to be a mathematical flow simulation model enabling the manager to test on a computer any hypothetical operational scenario and foresee the impact of his decisions. Nevertheless, the use of such a tool alone could not fully solve our problem; apart from a good understanding of the hydraulic behaviour of his canal, the manager had to be continuously aware of the present state of his system before making any decision (for example, in case of intermittent irrigation, the water levels in the respective reaches where

irrigation is going to start). He also needed systematic guideline procedures to induce tentative operational plans before testing them with the flow simulation model.

All these implications were taken into account by IIMI and CEMAGREF⁴⁵ researchers who concentrated their efforts in designing a simple management information system including a simulation model of flow and other decision-support modules. An essential prerequisite for designing this system has been a systematic analysis of the decision-making process.

UNDERSTANDING THE DECISION-MAKING PROCESS

From Decision Making to Implementation

The different steps sequentially listed below have to be considered as a continuous loop. At any given time, decisions taken for managing a system are based on its present state as well as the experience gained from its past functioning; the monitoring of the implementation and impacts of these decisions becomes the source of experience and support for the next round of decision making. Our tentative list of activities thus includes:

- Working out a water delivery schedule compatible with the available resources (forecasting), and using earlier planning decisions in terms of water allocation and the field conditions (optimization process).
- Obtaining information about the present state of the canal, such as the water levels in the different reaches, and the gate settings at the structures (data collection and management).
- Applying a set of rules and using past experience for designing a tentative operational plan, which can include prediction of the effectiveness of this plan if a simulation tool is available (optimization and simulation processes). This set of rules must explicitly take into account human resource constraints such as those in terms of staff concerned with implementation.
- Transmitting the plan to the field staff (communication).
- Controlling the implementation of the plan and its effectiveness by observing the state of the canal and comparing it with the targets (data collection and management).
- Evaluating the whole process of decision making and implementation to find out weaknesses and potential for improvements (data management and analysis).

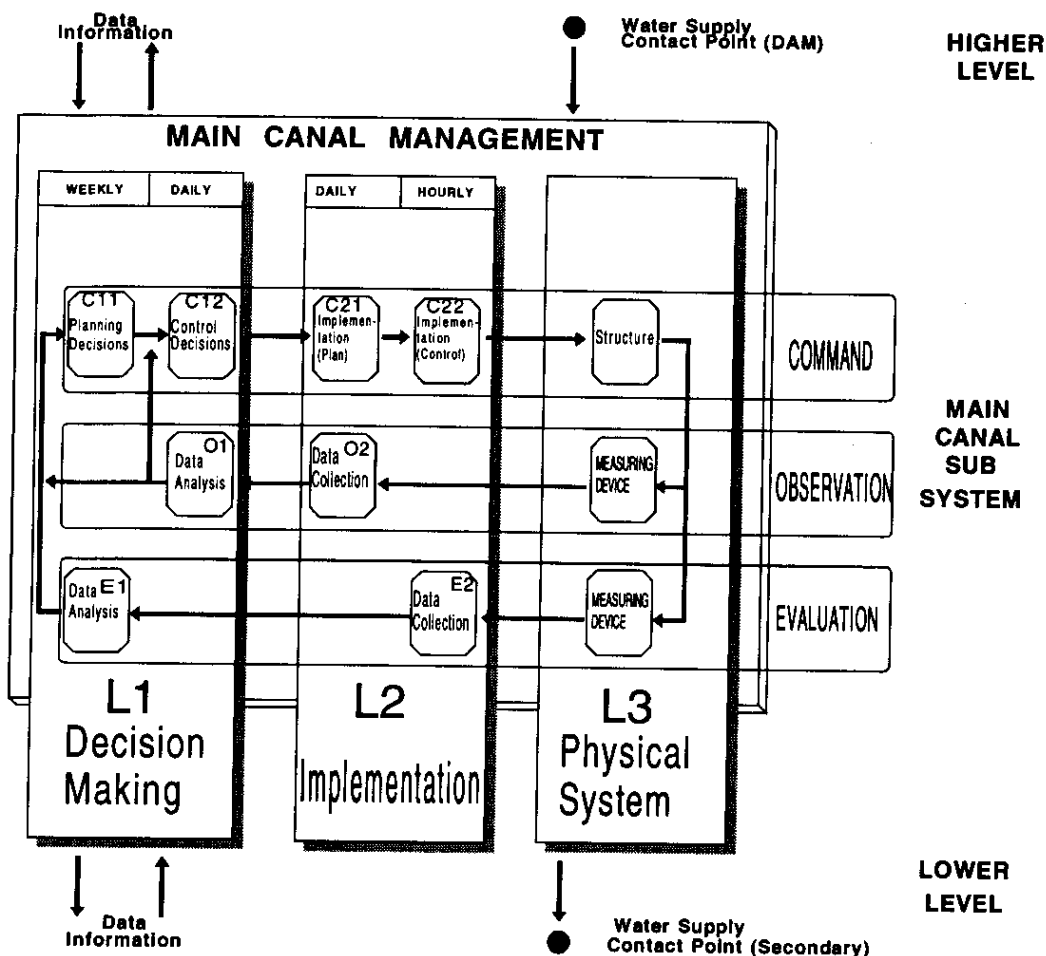
The effective fulfillment of these different steps in a sustainable and systematic way implies the availability of standard procedures and facilities to ensure easy access to field measurements, sharing of decisions with the field staff, control over the gate operations implemented and rapid use of past experiences.

⁴⁵ Centre National du Machinisme Agricole du Génie Rural des Eaux et des Forêts.

A Simple Framework for Canal Management

The management process explained above is summarized in Figure 8.4.

Figure 8.4. Framework for main-canal management.



As illustrated in the diagram, three main levels have been distinguished to represent the managerial context of the main canal:

1. People in charge of the whole decision-making process and the analysis of data (L₁).
2. People in charge of the local implementation process and collection of data (L₂).
3. The physical system encompassing the canal, its structure and irrigation water (L₃).

Three main functions, command, observation and evaluation, which split into various activities have also been identified.

Function of Command

- C11: The decision-making process regarding operational strategies (planning including target setting).
- C12: The decision-making process regarding real time adjustment and refining of operational strategies (control).
- C21: Routine implementation of instructions.
- C22: Handling perturbations at the implementation stage (local analysis).

Function of Observation

- O2: Collection of data (water levels, structure state).
- O1: Observation of the hydraulic state and behaviour of the system.

Function of Evaluation

- E2: Collection of data (operations implemented, time and amplitude).
- E1: Analysis of the performance of the water delivery process and estimation of potential improvements.

Any attempt at improving the management process as a whole must take into consideration the complete sequence of activities involved, leading to subsequent intervention where it is needed.

At the field level, the most important issues are to establish and sustain a reliable data collection network and ensure timely communications between the field staff and the center of decision making.

At the decision-making level, the most important issues are to develop a simple and efficient data storage and retrieval system as well as quick and systematic procedures for analyzing these data and generating relevant information for making decisions. The availability of relatively cheap computer technologies offers new opportunities to deal with these issues efficiently. Database management software, spreadsheets or specific applications such as simulation models can be integrated into simple and modular management information systems.

This approach is being tested in Kirindi Oya where changes have been introduced at both field level and manager level as described in the following section.

IMPROVING THE DECISION-MAKING PROCESS

Data Collection and Communication

First, the existing system for data collection and communication in Kirindi Oya was improved by replacing the earlier practices (delays in feedback to the decision center, manual filing) with systematic and timely procedures.

Basic data on water levels and gate openings are now collected at all structures operated along the main canal, including gated regulators and offtakes. These data are read and recorded twice a day by the gate keepers who send them to the work supervisors. The data are recorded in a standard form which is handed over by the work supervisor to the resident engineer on the same day. Water level readings are converted into discharges and stored along with the raw data in a computerized database. The main problems faced at this stage are to ensure reasonably accurate data collection and reliable discharge computation which imply careful calibration of the structures. In terms of communication between the decision maker and the field staff, a key improvement has been the daily contacts between the resident engineer and the work supervisors.

Computerized Decision-Support Tools

Second, different prototype computer modules have been developed and integrated to help in fulfilling the tasks described as L_1 (C_1 , O_1 , E_1). These modules comprise the database (Dbase III files, and entering and request procedures), the simulation model of flow, RBMC developed by CEMAGREF, and spreadsheets (Lotus 1-2-3).

One of the main constraints in developing this tool has been the need to interface the various modules to ease the transfer of data and results between them. Nevertheless, the facilities provided by the use of standard software enable any programmer to arrive at a reasonable degree of integration. A brief description of the tool developed is given in Annex 1. At this prototype stage, the intention was not to program a comprehensive commercial package but rather to give an example of a modular approach likely to be reproduced by other developers.

With the availability of the decision-support tools as well as improved communication between the decision maker and the field, the decision-making process as detailed earlier can be performed in a more systematic and efficient way. Next, in this paper, this process will be put into the perspective of a typical management problem faced by the irrigation manager in Kirindi Oya during the season yala 1991.

ILLUSTRATION OF THE DECISION-SUPPORT APPROACH

As an example of operational difficulties arising due to the crop diversification, the water delivery pattern implemented during the yala 1991 season is considered. Tracts 2 and 5 were under cultivation (pulses, chilies, onions) and the agreed schedule of water delivery was as in Figure 8.5.

This water issue pattern was new to the irrigation staff whose experiences referred mostly to rice cultivation. The questions raised were mainly:

- What would be an optimal pattern of water issues at the head sluice?
- How to operate the gated regulators in a coordinated way?

The operational concerns underlying the questions were the need to fill certain stretches of the canal prior to the start of water deliveries in case of a drop in water level between these issues, and the relative difficulty of ensuring a smooth transition of water deliveries from Tract 2 to Tract 5.

Figure 8.5. Water delivery schedule during 1991 dry (yala) season.

CANAL	ALLOCATION m ³ /s	Friday				Saturday				Sunday				Monday				Tuesday				Wednesday			
		6	12	18	24	6	12	18	24	6	12	18	24	6	12	18	24	6	12	18	24	6	12	18	24
TRACT 2																									
DC 1	0.028																								
DC 2	0.113																								
DC 3	0.085																								
FC 38	0.028																								
DC 4	0.085																								
DC 5	0.113																								
DC 6	0.085																								
DC 7	0.085																								
FC 68	0.028																								
DC 8	0.085																								
DC 9	0.085																								
TRACT 5																									
DC 1B	0.028																								
DC 1	0.028																								
DC 1A	0.057																								
BC 2	0.538																								
FC 48	0.028																								
DC 11	0.085																								
DC 12	0.085																								
DC 13	0.170																								

The decision-making process of the manager (activity C₁₁) before commencing the water issues of Tract 2 is described next. While the main steps of his analysis will be given here, the corresponding numerical results will be presented in the annexes. These results have been obtained *a posteriori* and have not been field-tested because most of the tools used were not yet available during yala 1991.

The manager first assesses the present state of the canal, paying special attention to the water levels in the reaches of Tract 2 (filling requirement); this is easily obtained by using the database (Activity O₁: observe water). He will then follow the process described as command operations in Annex 1, to work out the optimal main sluice issues pattern as well as an adequate sequence of gate openings to achieve his targets in terms of water levels at the gated regulators and discharges at the offtakes.

This process is detailed below:

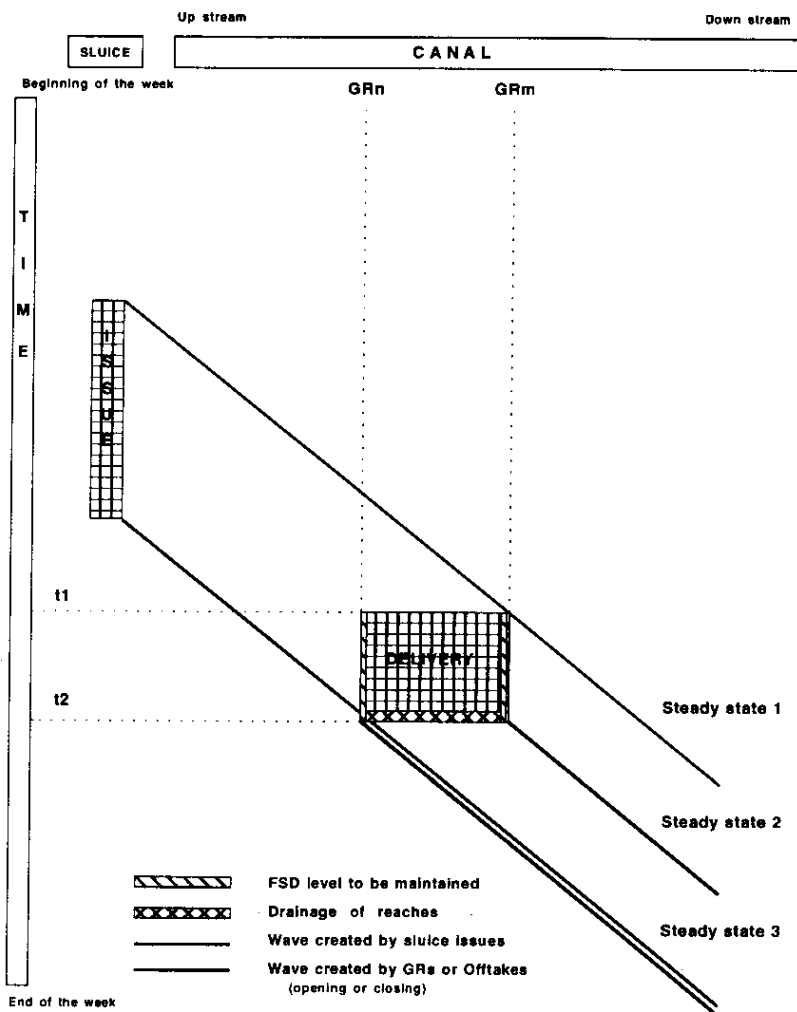
As mentioned earlier, before testing any operational plan with the simulation model, the manager has to combine his own experience with the use of simple decision-making modules (hydraulics optimization) to design a reasonably appropriate tentative plan and to avoid time-consuming, trial-and-error simulations.

The first module, based on the initial water levels in the canal and topographical data, gives information concerning the approximate time needed for filling the reaches in the parts of the canal where irrigation is going to start. Rough information about adequate gate settings at the gated regulators to fill the reaches in a coordinated manner is also provided (Annex 2).

The second module, based on the consideration of the water delivery schedule and the use of linear transfer functions roughly modeling the water propagation along the canal (diffusion and lag times) provides a first tentative plan for the water released at the main sluice (Annex 3).

Based on the water issue pattern at the main sluice and the water delivery schedule, the propagation of water along the canal is studied in order to provide some guidance concerning the time and amplitude of gate settings required to achieve the targets. This analysis is mainly done manually by studying a simple chart presenting a summary of the expected water delivery pattern. Some steady flow simulations are also used to generate indications about the optimal amplitude of gate openings required during the different stabilized phases of the water issues (Figure 8.6).

Figure 8.6.



Having following these three steps, a tentative operational plan for all gate settings along the canal (see Annex 4) is then available to be tested and evaluated by means of an unsteady flow simulation. Water levels and discharges at any point of interest along the canal are computed by the model and the results are evaluated in terms of achieved water deliveries at the offtakes and water level fluctuations in the main canal (Annex 5).

If considered as satisfactory, the plan is stored in the database and proposed for implementation; if not, the decision maker can revise it according to the weaknesses detected by looking at the simulation results and retesting it as many times as needed.

Most of the printed supports obtained by applying this process to our operational scenario have been presented in the annexes. The final plan described in these annexes would ensure satisfactory water deliveries.

The implementation of the plan (activity C₂₁) then needs to be carefully monitored (activities O₂, E₂) to allow proper control in case of perturbations (activity C₁₂) and, of course, a complete *a posteriori* evaluation (activity E₁).

CONCLUSION

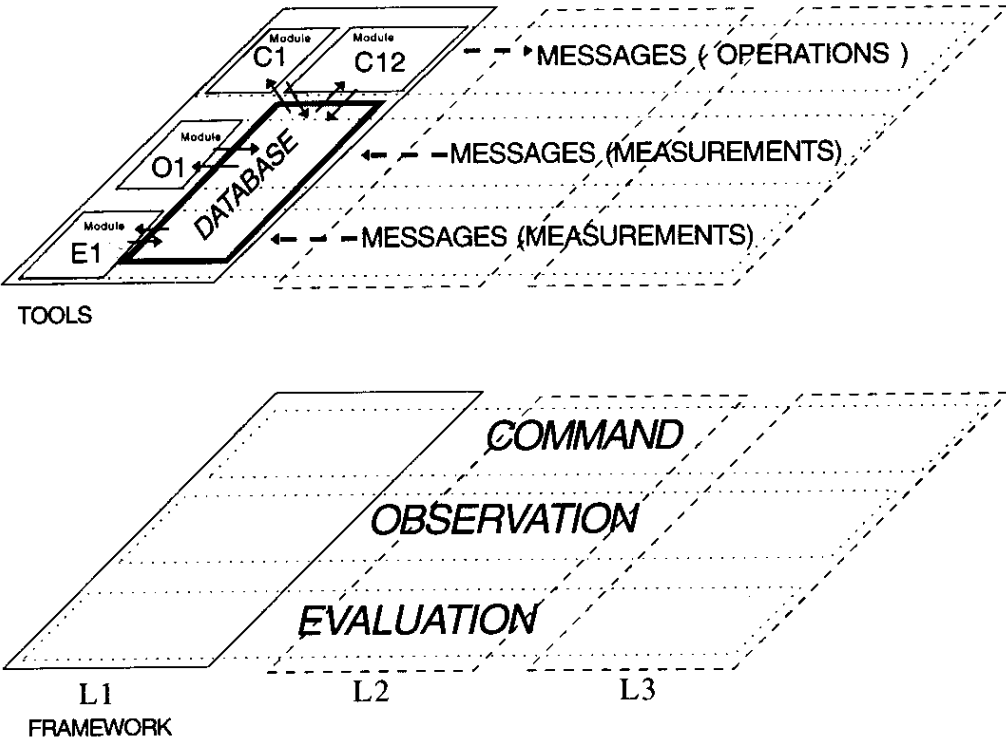
Several lessons have been already learned from the research conducted in Kirindi Oya; others are expected after full implementation of the decision-support package during the next irrigation season. The most important of these is probably the evidence that any attempt to improve the decision-making process of an irrigation manager has to be done with full awareness of the technical and managerial constraints relating to the data collection and communication systems in use. A sustainable introduction of decision-support tools implies upgrading the existing setup as a prerequisite condition.

A second aspect relates to the nature of the proposed tools. It is probably worthwhile to insist again on the absolute necessity to make these tools modular, easily interfaced with simple database management software and leaving some room for customization by the manager. Within this context, computerized information, simulation and optimization techniques have certainly a key role to play in future improvements likely to occur in the management of main canal systems.

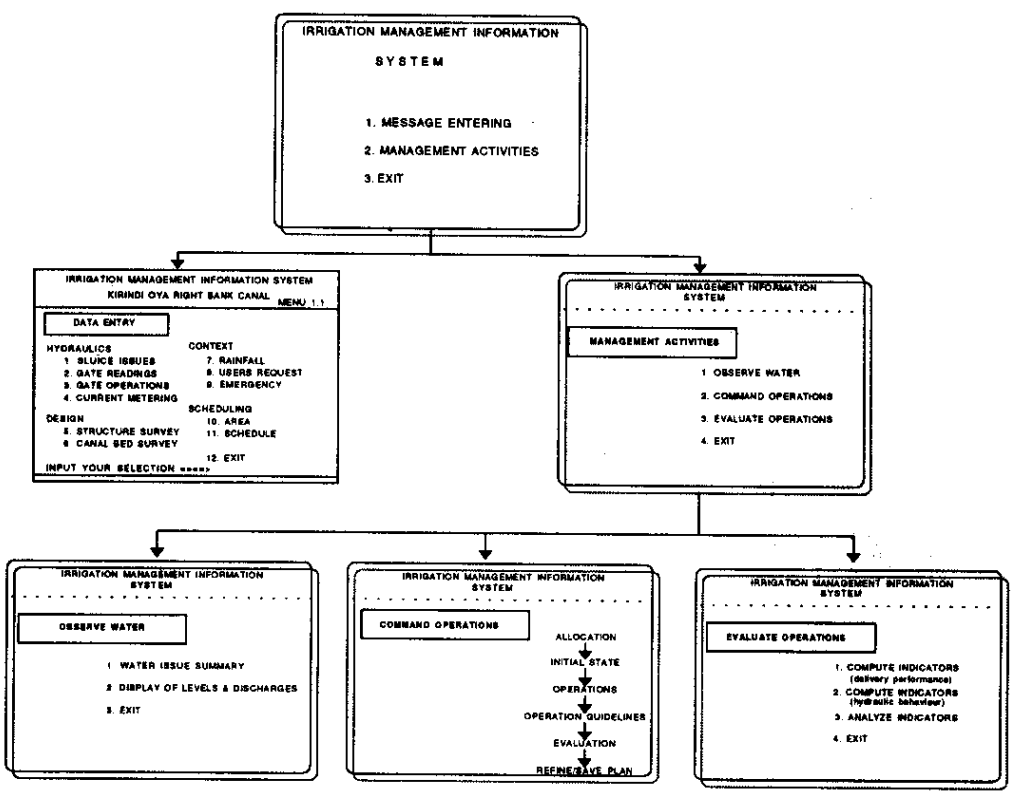
Annex 1

**Simplified Layout
of the Management Information System**

Various modules can be developed for assisting the decision-making process, derived from the framework representing the management process:



The first main menus of the prototype tool are as follows:



Annex 3

Module, Main Sluice Issue

The main hydraulic factors to be considered to release water at the main sluice are:

- The time of propagation of water (lagtimes).
- The phenomena of diffusion (attenuation of discharges peaks).
- The phenomena of storage/drainage in the various reaches due to gated regulator operations.

Given the targeted discharges at the offtakes and the main hydraulic conditions of the scenario (low or normal water depth and low, average or high base discharge), a rough estimation of the main sluice issue pattern is computed by considering the inverses of simple linear transfer functions calibrated *a priori* for each stretch of the canal according to the type of hydraulic scenario studied. The interface of the spreadsheet used for this purpose as well as the proposed pattern corresponding to our operational situation are given below:

INTERFACE

- THIS SHEET ALLOWS YOU TO COMPUTE AN APPROXIMATION OF THE MAIN SLUICE ISSUES SATISFYING YOUR OBJECTIVES:

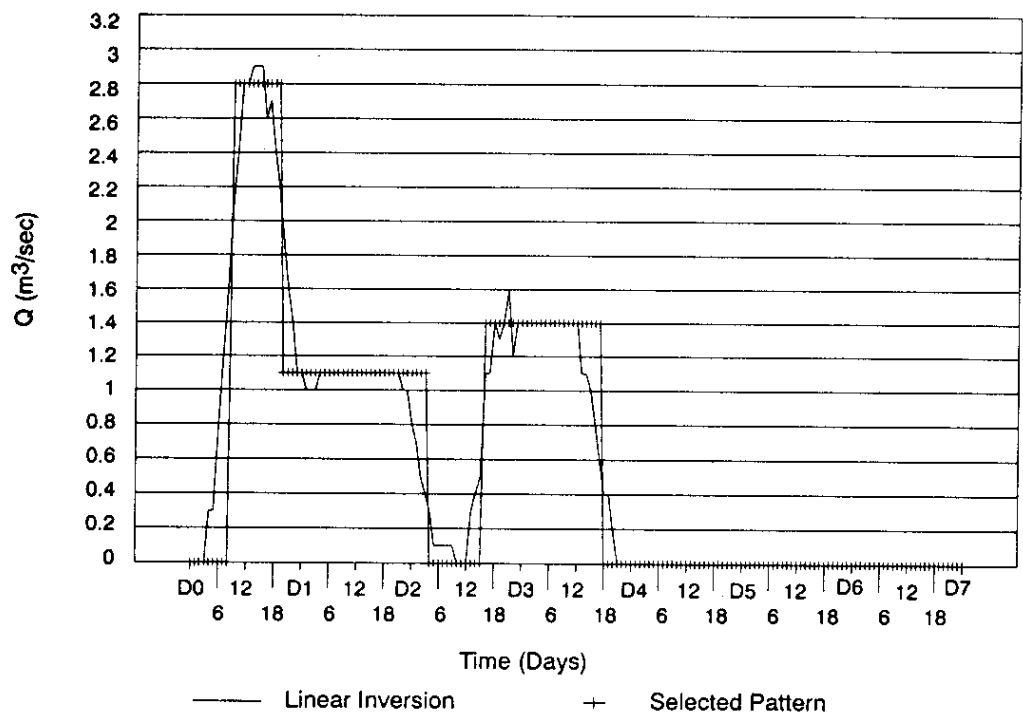
- * ROUGH LINEAR INVERSION
- * INCLUDING SEEPAGE LOSSES
- * INCLUDING FILLING PHASES
(AS DEFINED IN T1C2VOLM.WK1)

RUN THE MACRO \O AND COME BACK TO THE BASIC DATA BLOCK BELOW IN ORDER TO FINALIZE YOUR MAIN SLUICE ISSUES.

MAIN SLUICE ENVISAGED OPERATIONS AND EVALUATION:

VOLUME NEEDED:		364217 M3			
VOLUME PROPOSED:		368640 M3			
NBOP:	!	DAY:	HOUR:	DIS.: (M3/S)	!
	!				!
1	!	0	0	0.00	!
2	!	0	9	2.80	!
3	!	0	20	1.10	!
4	!	2	4	0.00	!
5	!	2	16	1.40	!
6	!	3	18	0.00	!
7	!	6	0	0.00	!

MAIN SLUICE ISSUE

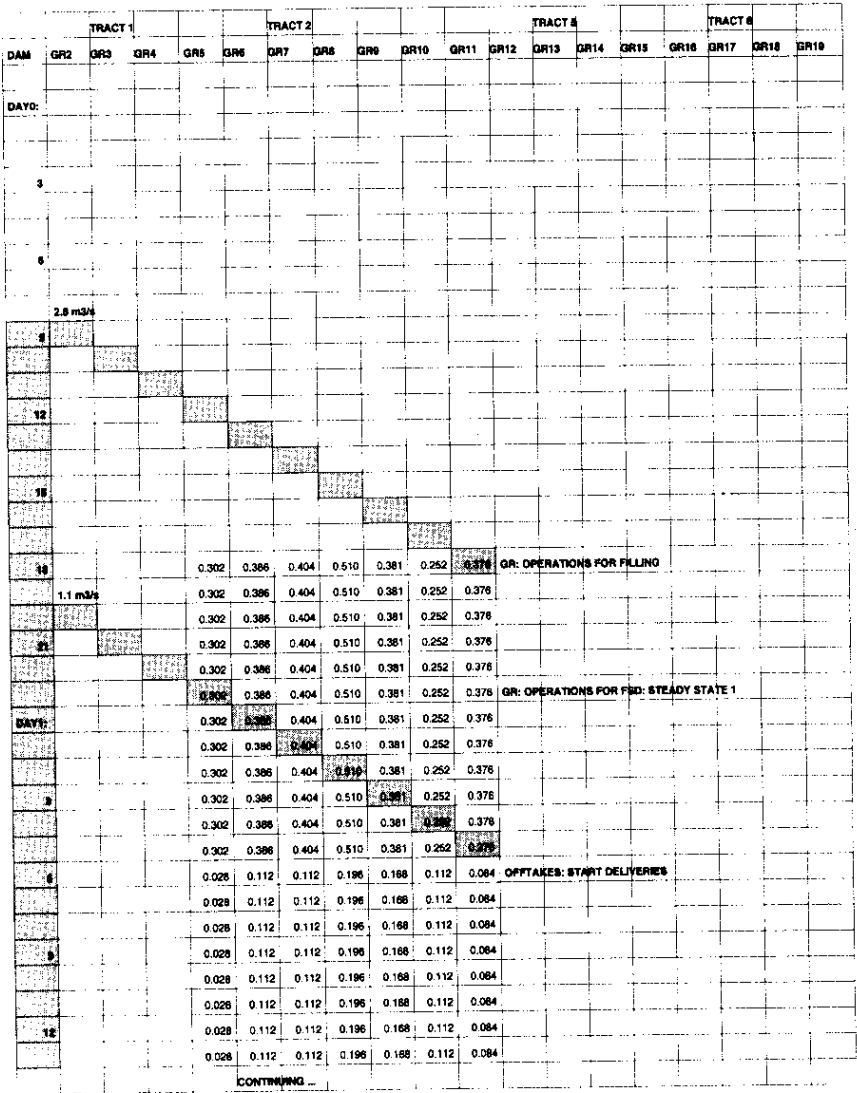


On the graph, the final pattern of water release chosen is made of 2 phases of continuous issues plus an initial increment at a higher discharge in order to fill Tract 2. Tract 5 will be filled by draining Tract 2 after its delivery period (the water levels are kept low in the portion of canal commanding Tract 2 once the delivery period is over).

Annex 4

Proposed Operational Plan

After the various aspects relating to the filling phases and the main sluice releases are studied, the objective of the manager is to find out an appropriate sequence of gate settings at the gated regulators and the offtakes. A partial printout of the chart used for this purpose is presented below with the first operations resulting from the manager's analysis. The numbers indicated below each gated regulator (GR) represent the total demand in the reach upstream of this GR in m³/s (demand for filling or deliveries at the offtakes).



A set of rules allows the manager to work out his first strategy regarding the timing of gate operations. Using the wave chart, the following method can be applied:

- a. Locate the periods during which the water level has to be controlled (FSD) at the gated regulators.
- b. Locate the periods during which the gated regulators are fully open (in case of drainage of certain reaches after deliveries).
- c. Locate the wave propagation:
 - created by main sluice issues
 - created by the opening of certain gated regulators
 - created by the closing of offtakes (end of deliveries)

The speed of the waves (slope of lines in the chart) is roughly provided by the analysis mentioned in Annex 3 (in this scenario, approximately 1 hour per reach).

The first set of rules then becomes:

1. Adjust gated regulators before establishment of each FSD period.
2. Adjust gated regulators if a wave crosses a FSD period.
3. Adjust gated regulators in case of a severe wave liable to cause overtopping.

An indicative amplitude of the gate adjustment needed is then searched. This can be achieved for the 3 cases mentioned above using the steady state unit of the simulation model which can provide an optimal set of gate settings given:

- The delivery pattern at offtakes.
- The discharge in the main canal (estimate in case of drainage waves).
- The targeted water levels at the gated regulators.

The tentative operational plan is then finalized (see standard printouts for Tracts 2 and 5 below). The operations are given in the format, day/hour/amplitude, and can then be tested with the simulation model of flow.

The RBMC software allows neither the hydraulic computations under dry bed conditions nor tolerate supercritical flow conditions. It is thus difficult to simulate an operational scenario which implies very low main sluice discharges. In this example, the issues at the main sluice have been kept to a minimum rate of $0.5 \text{ m}^3/\text{s}$ to compensate for the seepage losses along the canal for the two intermediate phases even if a complete closure would have been appropriate.

RBMC WATER DELIVERIES - PROPOSED OPERATIONAL PLAN - TRACT 2	WEEK: YALA 91
(DAY/TIME/amplitude)	

	OP 0	OP 1	OP 2	OP 3	OP 4	OP 5	OP 6	OP 7
N.Shots	.500	001090012.8	001200011.1	021040010.5	021160011.4	031180010.5	041120010.0	
D 1	.000	01 0600 0.05	02 1200 00					
QR 5 G1	1.50	00 1800 0.84	00 2300 0.38	02 1200 1.5				
G2	1.50	00 1800 0.00	02 1200 1.5					
G3	.000							
G4	.000							
G5	.000							
D 2	.000	01 0600 0.08	02 1200 00					
QR 6 G1	1.50	00 1800 0.72	00 2300 0.30	02 1200 1.5				
G2	1.50	00 1800 0.00	02 1200 1.5					
G3	.000							
G4	.000							
G5	.000							
D 3	.000	01 0600 0.10	02 1200 00					
F 34	.000	01 0600 0.06	02 1200 00					
QR 7 G1	1.50	00 1800 0.54	00 2300 0.11	02 1200 1.5				
G2	1.50	00 1800 0.00	02 1200 1.5					
G3	.000							
G4	.000							
G5	.000							
D 4	.000	01 0600 0.12	02 1200 00					
D 5	.000	01 0600 0.14	02 1200 00					
QR 8 G1	1.50	00 1800 0.35	00 2300 0.02	02 1200 1.5				
G2	1.50	00 1800 0.00	02 1200 1.5					
G3	.000							
G4	.000							
G5	.000							
D 6	.000	01 0600 0.07	02 1200 00					
D 7	.000	01 0600 0.11	02 1200 00					
QR 9 G1	1.50	00 1800 0.21	00 2300 0.02	02 1200 1.5				
G2	1.50	00 1800 0.00	02 1200 1.5					
G3	.000							
G4	.000							
G5	.000							
F 68	.000	01 0600 0.16	02 1200 00					
D 8	.000	01 0600 0.37	02 1200 00					
QR 10 G1	1.50	00 1800 0.12	00 2300 0.04	02 1200 1.5				
G2	1.50	00 1800 0.00	02 1200 1.5					
G3	.000							
G4	.000							
G5	.000							
D 9	.000	01 0600 0.09	02 1200 00					

RBMC WATER DELIVERIES - PROPOSED OPERATIONAL PLAN - TRACT 5

WEEK:

YALA 91

(DAY/TIME/amplitude)

OP 0	OP 2	OP 4	OP 6
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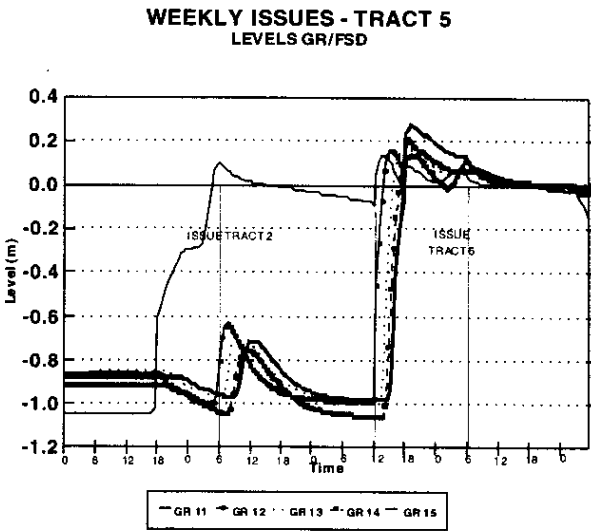
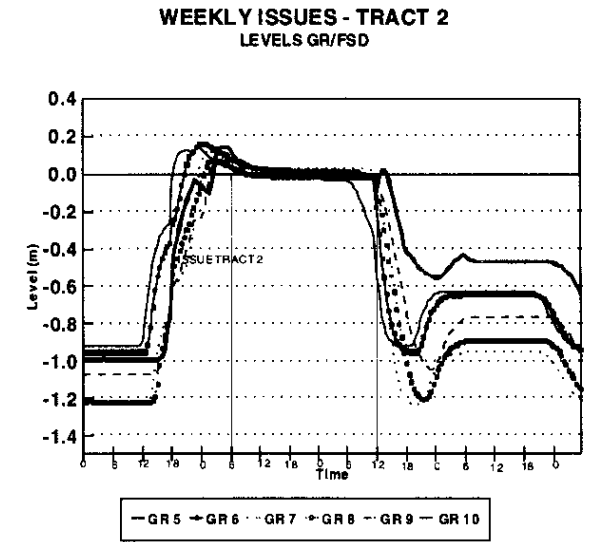
.500	001090012.8	001200011.1	021040010.5	021180011.4	031180010.5	041120010.0
------	-------------	-------------	-------------	-------------	-------------	-------------

D 1B	.000	03 0800 0.05	04 0800 00			
	1.50	00 1800 0.04	02 1200 1.00	02 1800 0.10	03 0600 0.36	04 0600 1.5
	1.50	00 1800 0.00	02 1200 000	04 0800 1.5		
	.000					
	.000					
D 1	.000	03 0800 0.06	04 0600 00			
D 1A	.000	03 0800 0.18	04 0600 00			
BC 2	.000	03 0800 0.38	04 0600 00			
	1.50	02 1200 1.00	02 1800 0.13	04 0600 1.5		
	1.50	02 1200 0.00	04 0600 1.5			
	.000					
	.000					
F 48	.000	03 0800 0.06	04 0800 00			
F 49	.000					
D 9	.000					
F 54A	.000					
F 54	.000					
	1.50	02 1200 1.00	02 1800 0.21	04 0600 1.5		
	1.50	02 1200 0.00	04 0600 1.5			
	.000					
F 55	.000					
D 11	.000	03 0600 0.06	04 0600 00			
	1.50	02 1200 1.00	02 1800 0.12	04 0600 1.5		
	1.50	02 1200 0.00	04 0600 1.5			
	.000					
D 12	.000	03 0600 0.15	04 0600 00			
D 13	.000	03 0600 0.18	04 0600 00			
	1.50	02 1200 1.00	02 1800 0.05	04 0600 1.5		
	1.50	02 1200 0.00	04 0600 1.5			

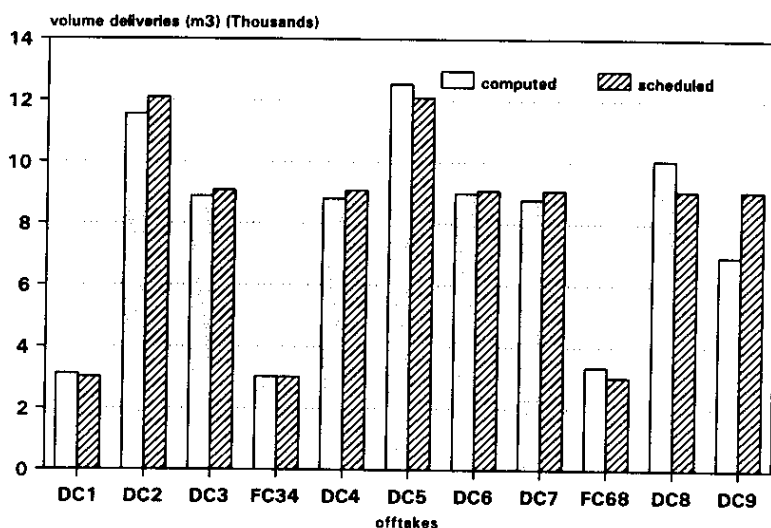
Annex 5

Evaluation of the Proposed Operational Plan

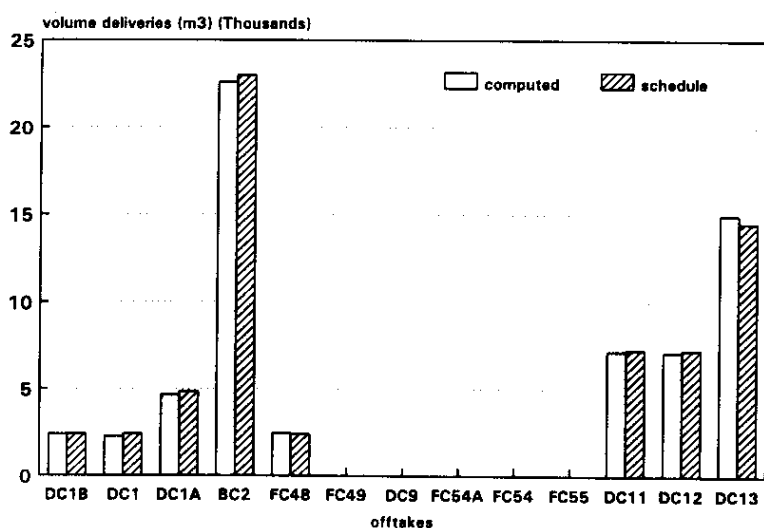
The fluctuations of water levels at the gated structures and the gap between targeted and achieved discharges at the offtakes have been kept as relevant criteria for evaluating the operational plan. The evaluation, accomplished after using an unsteady flow simulation, is summarized below by means of 4 graphs:



ADEQUACY WATER DELIVERIES TRACT 2



ADEQUACY WATER DELIVERIES TRACT 5



The operational plan adopted proved to be acceptable even if some improvements could be introduced. For instance, the transition phase between the Tract 2 and Tract 5 deliveries reveals a significant increase in water levels along Tract 5 which could be minimized by limiting the drainage of Tract 2. The method presented is in fact largely suboptimal and leaves room for various alternatives which can be tested by the manager.

CHAPTER 9

Towards Participatory Management: The Case of an Irrigation System in the Plains of Nepal

***Ujjwal Pradhan, Alfredo Valera
and
Durga K.C.***

INTRODUCTION

THE GOVERNMENT OF Nepal views improved irrigation management as crucial to its rapid development program. Better management is now being viewed in terms of progressively reducing the role of the state and enhancing farmer participation. In 1991, it introduced a set of policies aimed at enhancing farmer participation in irrigation management (Approach to the Eighth Five Year Plan 1991).

Earlier, in 1988, the government adopted a new policy on irrigation development (Working Policy on Irrigation Development for the Fulfillment of Basic Needs 1988) to facilitate urgent and effective action in the irrigation sector to achieve the set goal. This working policy provided new direction to Nepal's irrigation development by mandating the participation of farmers at all levels of development, from project identification, design and construction to operation and maintenance (O&M) of completed systems.

This policy was to be implemented by means of two action plans — one for turning over some systems constructed and managed by the Department of Irrigation (DOI) to farmers for O&M, and the other to increase participation of farmers in the management of jointly managed systems. The objectives of the Action Plan for Participatory Management are “to share the system O&M responsibilities of large-scale irrigation systems between the water users' organizations (WUO) and the irrigation agency.”

The various objectives of the existing policies and action plans were recently consolidated into a new irrigation policy. With the change in political climate, various partners in development, including government agencies, have been guided towards a decentralization and democratization movement in their activities. Thus, the new policy has two of its objectives specifically designed to support local initiative and control with a great shift in responsibilities from state to locality. The new policy is intended to “maximize the involvement and participation of users (without affecting the intended impacts of the project in each phase of implementation) so as to decrease government responsibilities in irrigation implementation and instead promote local resource mobilization for construction, maintenance and repair by the users themselves” and to “promote and support self-reliant private sector development of irrigation development and expansion by Nepali farmers themselves.”

The new Water Resources Act has a very important feature of setting up a hierarchy of water use rights. Water users' associations (WUAs) can now have legal recognition derived from this

very Act whereas earlier WUAs were to be registered under the Association Act. The new Act also makes provisions for the complete ownership of systems that are turned over to the farmers. Yet, the Act is silent regarding the "co-ownership" of jointly managed systems.⁴⁶ It is hoped that the proposed irrigation rules and regulations to be derived from this new Act are not bound by rights and duties from the point of view of the state or agency irrigation management but extended to cater to the balanced "rights and duties" on the part of water users' groups. The previous regulations bestowed power to agency management and did not focus on the rights of WUAs (e.g., defensible water rights) to participate in planning and implementation of any construction (at least at the micro-level), the right to information about water availability, the right to timely and reliable supply of water, etc.⁴⁷

In many countries in South and Southeast Asia, participatory management has been advocated as a distinct policy for irrigation development. It has been noted that traditionally, in many countries, indigenous irrigation has been managed effectively by water users who design, build, operate and maintain these irrigation systems (usually small-scale systems). Uphoff (1986) notes that more recently, in connection with government development programs, the planned introduction of water users' associations is increasing with some notable success. The inclusion of farmers in the decision-making process of management of irrigation systems is now accepted as necessary to increase productivity and income among the poor in the Third World (Raby 1991). Raby (1991) points out that farmer participation is not simply an advocacy call for empowerment and mobilization of a hitherto powerless group but, more fundamentally, a development strategy in itself. Farmers are no longer considered as the passive recipients of development activities but as active participants and, in some cases, as equal partners.

Uphoff (1986) has elaborated and analyzed the nature, rationale, and approaches of farmer participation as the agency-farmer relationships. Others like Singh (1991) and Pearse and Stiefel (1980) have also critically looked at the nature of participation. Bottrall (1981) points out that the management of irrigation projects should be considered as an evolutionary process, with a progression over time from a relatively high degree of central control towards increasing farmer participation and autonomy of decision making. Participatory management approaches have been introduced in countries like the Philippines, Sri Lanka and Nepal with relative successes (Korten and Siy 1989; Raby 1988; IIMI 1986; and IIMI 1992).

This paper presents the process developed in facilitating the formation of water users' groups in the Banganga Irrigation System and its consequent outcomes in terms of O&M benefits.

BACKGROUND⁴⁸

The International Irrigation Management Institute (IIMI) was requested by DOI to assist in the development and implementation of the action plan on participatory management. The Banganga Irrigation System (BIS) was identified as the field site for IIMI to work collaboratively with DOI

⁴⁶ In an earlier draft of the bill, Article 1 of the Law on Land Reclamation of the *Muluki Ain* (Penal Code) was proposed to be repealed. Such a legal annulment posed the problem of the existing customary and traditional rights being in jeopardy.

⁴⁷ Ambler (1992) presents a good set of water users' rights. He proposes rethinking on notions regarding farmer "participation" or "involvement" and, especially, the types of lip service usually provided while "undertaking" the "needful" institutional development of the WUOs.

⁴⁸ IIMI carried out this project from May 1991 to July 1992. During IIMI's involvement with this project, the irrigation policy and the Water Resources Act were only in draft form and were being reviewed by the government.

staff in developing and testing ways for establishing an O&M plan through more water user participation. This collaborative project was supported by the Agricultural and Rural Development Office of the United States Agency for International Development (USAID) mission to Nepal.

The Banganga Irrigation System was one of the subprojects that was rehabilitated under the Command Area Development Project (CADP) during the period 1982-89. Under this project, the reservoir was enlarged, the main canal improved, tertiary facilities constructed, support services to farmers initiated, water users' groups formed at the tertiary block level (but were found ineffective), and the irrigation management plan developed. However, the management plan has not yet been implemented and the water users' groups formed were found to be nonfunctional (ADB 1990). At the start of the project, the BIS management was operating under a project mode directly under the Western Regional Irrigation Directorate (WRID) but was finally merged with or transferred to the District Irrigation Office (DIO).

The three major component activities of the IIMI participatory management program in Banganga Irrigation System were: i) DOI-Farmer Dialogue; ii) Water Users' Group Formation and Farmer Training; and iii) Management of the Main System.

System Background

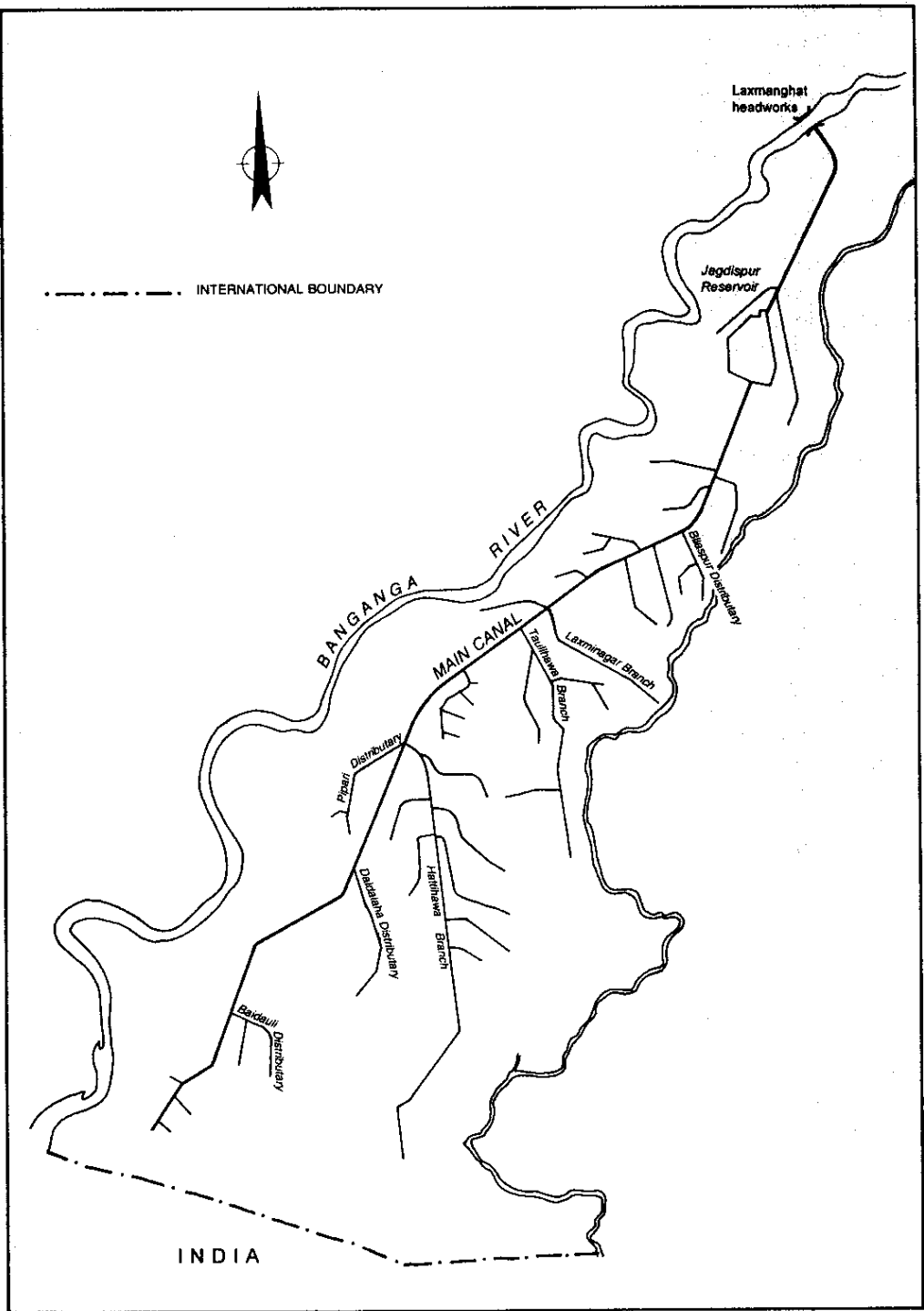
The Banganga Irrigation Project is a government-built irrigation system which is located in Kapilbastu District of the Terai in the Western Development Region (Figure 9.1). The history of Banganga Irrigation System (BIS) can be divided into three periods: i) pre-government construction of the canal, ii) irrigation system construction by the government, and iii) improvement under the Command Area Development Project.

Before government construction of the present Banganga Irrigation System, farmers used to build temporary brush and stone diversions at various places along the river to obtain irrigation water. The depressed land at Jagadishpur was converted into a reservoir, and a canal was built from it with *corvee* labor during the Rana Regime sometime in the 1940s. That canal was known as the Raj Kulo. According to the old villagers of the Banganga area, there were other scattered irrigation systems drawing water from the Jamwar Stream aside from the Raj Kulo. Therefore, the farmers around Banganga do have experience in irrigation.

During those days, the Raj Kulo was looked after by the office of Bada Hakim (the then chief administrative officer of a district). There was a *khardar* (government official) appointed at the Bada Hakim's office in Taulihawa for the purpose of water management of the Raj Kulo. He looked after the operation of this system and mobilized people for maintaining the diversion weir and other structures. The *zamindars* (big landlords) took care of other systems.

Initial construction of the post-Rana System was completed in 1978. This project was undertaken to provide irrigation to some 6,000 ha of cultivable land. In 1982, this project became the Command Area Development Project (CADP) with funding support from the Asian Development Bank. The reservoir was enlarged, the main canal improved, tertiary facilities constructed, support services to farmers initiated, water users' groups formed at the tertiary block level, and an irrigation management plan developed.

Figure 9.1. Banganga Irrigation System.



THE PROCESS FOR THE FORMATION OF WATER USERS' ORGANIZATIONS

The process that IIMI-Nepal staff followed to facilitate the formation of water users' groups in the pilot area of BIS comprised a series of steps which can be broadly categorized under: i) preliminary observations on system management, ii) observations on farmers' cooperation, iii) continuous dialogue and meetings with farmer groups and agency staff, iv) assisting in the formation of water users' groups, v) farmer-to-farmer training, and vi) continuing dialogues with agency staff and farmer groups to strengthen water users' groups.

Preliminary Observations on System Management

The initial activity focused on trying to understand how irrigation management activities were being undertaken. Specifically, the water delivery performance as practiced by the system management was assessed. Several fields were selected within certain outlets (to represent the head, middle, and tail areas) to assess the source of irrigation water and farm cultivation practices. Simultaneously, the performance of the already established water users' associations and federations (during the time of CADP) was assessed by the field team by observing group activities related to irrigation practices, the organizational setup of the groups, the rules and regulations formulated regarding water use, allocation, distribution, resource mobilization or contribution, and procedures for conflict resolution.

Observations on Farmers' Cooperation

IIMI staff met and convened the different water users from the "defunct" water users' groups or federations and discussed irrigation management issues and their current practices regarding the use of irrigation water. Often, meetings were held with only the so-called committee members, or with only the users, or with both. Some agency staff members also attended these meetings and invariably dialogues ensued between the agency and the farmers. Often, meetings ended with the two parties not agreeing with one another. However, at the urging of IIMI, both parties continued to meet with each other at the field site and also at the system management office.

The rationale and ideas pertaining to participatory irrigation management were discussed during these meetings. Both the farmers and the agency staff slowly began to appreciate the need for organized farmers and an agency staff supportive of these ideas. Within a sub-command area, tail enders did not receive adequate water and these people doubted that the head enders would cooperate so that they would get water from the outlet. The agency staff were skeptical that the farmers would organize themselves to do anything cooperatively since the agency had, in the previous year, wanted the farmers to mobilize their resources to clean the canals. Even within a single outlet or distributary, people were divided among themselves. Those who, by the location of their fields in the irrigation system, received water with comparative ease were uncooperative and the tail enders were skeptical about the utility of their efforts if the head enders were not going to be supportive of them.

Continuous Dialogue and Meetings

IIMI held several meetings with different groups of farmers and tried to convince them that if they got together and started to clean the canal they would be able to receive water more smoothly (especially the tail enders). For example, in the Bilaspur Distributary, the users from Harrahawa area, the tail enders, were enthusiastic about cleaning the canal but had wanted the head and middle enders also to cooperate as a single unit. One member of the agency staff, the second in command within the agency, along with IIMI field staff, convened a group meeting of the users from all the three villages that are within the command area of the distributary. The types of discussions and debates among the users themselves and between users and the agency staff were symptomatic of the estranged relations between them.

The users questioned why they should work on the canal when hardly any of their concerns regarding alignment and outlets were listened to by the agency staff. Several users were suspicious of the agency because, earlier, the maintenance work was done by contractors. The users felt that the work done by the farmers would then be registered as work done by contract workers and the agency could then pocket the money paid for the work done. The farmers were very suspicious of the motive and intention behind the request for them to do maintenance work. The agency representative informed the farmers that a lot of investment had been made by the government and now it was unable to carry out continuous maintenance work. The construction phase was over and according to the government's working policy, emphasis was being put on participatory management which also included maintenance work on the part of the water users. The farmers did not care what the government policies were, because they were distrustful of the agency and perceived all these requests for water user "participation" in cleaning the canal only as added responsibilities. Thus, this specific meeting within the Bilaspur Distributary broke up due to tension, "mutual" distrust, doubts about each others' intentions, and the inability to come to an agreement.

Then the IIMI field staff requested only the water users to meet them without any representations from the agency. When they met, the water users decided to cooperatively clean up their distributary canal to ensure smooth flow of water for everyone and the usual conflicts and anger that accompanied water delivery to that canal were reduced. However, when cleaning began, it was very much on an informal uncoordinated way. Many landowners next to the canal were mad at those maintaining the canal because soil and mud from their land was used to repair the canal and stop leakages. The farmers and the adjacent landowners wanted someone from the irrigation office (the agency) to supervise the canal work. A fieldman was sent by the office for supervision but heated discussions and allegations ensued when some users again raised their doubts about the sincerity and integrity of the agency staff. The agency staff members were accused of being corrupt and the fieldmen wanted the farmers to fail in their enterprise so that the agency would then revert to the old system of awarding contracts and would thus not have to deal with belligerent users. Because the users did not have an effective organization, the canal work was very informal, uncoordinated, and haphazard. The users felt the need for an effective organization. The question raised was whether to strengthen the water users' groups and the federation "created" during the CADP era or to restructure them or found newer groups based on different criteria.

Despite an ineffective organization, the users of this area were able to clean their canal much to the satisfaction of the members and surprise of the agency staff who did not believe farmers can ever organize themselves for irrigation activities, especially for maintenance work. The catalyst that "forced" the users to rethink their irrigation practices and create an awareness for the need of an effective organization and group action was brought about by their experience while cleaning their canal and dealing with the agency in the process. The formation of the water users' group (WUG) and the selection of its functionaries did not take place for at least one whole year.

Assisting Formation of Water Users' Groups

An added strategy employed by IIMI to facilitate the process of WUG formation was the farmer-to-farmer training program in which the participants were not only the farmers but also the agency staff who were skeptical about the efficacy and effectiveness of farmers' capabilities and organizational strength. In several places in Nepal, farmer-to-farmer exchanges have proven to be very useful in strengthening water users' organizations (Pradhan and Yoder 1989). IIMI felt that farmers could relate to one another since they shared more or less the same experiences. The example of farmers who were performing and managing irrigation activities well was a stimulus to others to get organized and control their own resources. It was felt that visits to well-managed irrigation systems and dialogue with irrigators from such systems had served as eyeopeners to the farmers. Farmers were more willing to listen to suggestions made by fellow irrigators who had already adopted these suggestions. Such farmer-to-farmer exchanges and training not only showed the possibilities for the formation of strong irrigation/water users' groups but also exposed the trainee farmers to the nature and role of the internal structures and dynamics of irrigation organizations.

Farmer-to-Farmer Training

Farmer-to-farmer training was conceived as one possible approach to bring about participatory management in the Banganga Irrigation System. The training was proposed to facilitate the transfer of experiences from farmers in well-managed irrigation systems (Chattis Mauja and Pithuwa systems) to those in poorly managed systems like Banganga through site visits, discussions, and exchange of ideas.

IIMI proposed the need for such training for the farmers of the Banganga Irrigation System because several differences between the BIS officials and farmers regarding water management problems and issues had been identified. There were occasional disagreements between officials and farmers regarding the water distribution schedule. Farmer organizations of CADP were found to be ineffective in water management activities. The farmers were of the view that they did not own the system because, government financing and project planning and the use of contractors had been predominant. There was poor communication and coordination between the farmers and the irrigation staff.

Twelve farmers were selected for training by the farmers themselves during meetings called by the IIMI field staff and the agency. The system manager and a fieldman were included in the exchange field visit so as to provide exposure to irrigation staff members regarding the capacity and potential of the farmers. Such joint field visits facilitated interaction between the agency staff and farmer representatives.

Continuous Dialogue to Strengthen Water Users' Groups

Several WUGs had already been formed by the users themselves before the farmer-to-farmer exchange program was implemented. The objective of the continuous dialogue and meetings with the different groups and factions of users undertaken by IIMI was to facilitate dialogue between the users themselves to form WUGs by themselves. However, after the exchange visits, the trainee farmers informed their fellow farmers what they had learned, seen, and discussed during their

visits. Several WUGs were newly formed and in the existing WUGs, new rules, regulations, and roles were established with the objective of strengthening their organization. Not only were the farmers motivated to form or restructure WUGs but the system manager himself, after having returned from the field visit, began facilitating the formation of new WUGs outside the research area.

Thus, in short, IIMI stressed the fact that the formation of water users' groups can only be done by the farmers themselves and that outsiders can only facilitate the process. It was, therefore, important to create an environment that brought about awareness amongst uncoordinated and unorganized farmers of the need for an organization. This was partially brought about by the IIMI field staff who discussed with farmers the issues they face regarding collective action. IIMI field research staff first observed the behavior of both the agency and the farmers and their interactions with one another. They also interacted with the farmers every week and in the process brought about interactions between and among groups of farmers themselves. During such meetings, the objectives of participatory management and the need for the involvement and participation of farmers in the management of irrigation activities within their subcommand areas were emphasized.

A participatory management program at the BIS assisted in the formation of thirteen WUGs. Each WUG committee consists of a chairperson, vice-chairperson, secretary, treasurer and patrolman selected by the farmers during a general assembly. The DOI staff often participated in these assemblies. The active participation of the DOI staff members, especially the project manager and the DIO chief was very crucial in facilitating confidence in the participatory management program. The farmers and the agency staff saw each other as willing partners to involve each other in the management of the system. Minutes of the general assembly recorded the WUG duties and responsibilities. WUGs were formed based on both hydrological and village boundaries depending on which ones the co-irrigators felt were most appropriate. The WUG members stipulated that a WUG committee member must be: 1) an irrigator within the outlet, 2) a village resident, 3) experienced in water management activities, 4) respected by the community, 5) able to mobilize resources for operation and maintenance (O&M), and 6) minimally involved with party politics.

WUGs defined their responsibilities as: 1) forwarding requests for water, seeds and other inputs to the BIS management, 2) mobilizing resources for system O&M, 3) supervising canal maintenance and cleaning, 4) keeping minutes of meeting, records of irrigation activities and financial accounts, 5) collecting fines, 6) allocating and distributing water according to the water distribution schedule, 7) holding regular meetings, 8) resolving water conflicts, 9) implementing rules and regulations, 10) establishing good communication between the farmers and DOI, and 11) assisting with the preparation of the water distribution schedule. Each WUG has formulated rules and regulations with the assistance of the DIO staff. The rules are still evolving as the farmers call meetings when necessary to discuss the rules. Fines have been instituted and collected for violation of rules.

SPECIFIC OUTCOMES OF FARMER PARTICIPATION ON BIS IRRIGATION ACTIVITIES⁴⁹

The specific outcomes of farmer participation on irrigation activities in Banganga can be outlined as follows:

⁴⁹ For details see IIMI 1992a.

Table 9.1. Labor contribution of water users' groups (WUGs) for canal maintenance in the Banganga Irrigation System, monsoon season, 1991.

Serial No.	Name of WUG	Location within system	Length (km)	Area (ha)	Total labor days	Total cost (NRs)
1	Bilaspur	Head	4.50	212.03	600	19,200.00
2	Semari	Head	2.50	77.23	130	4,160.00
3	Gobari	Head	3.50	89.23	207	6,624.00
4	Tilaurakot	Head	4.00	70.17	195	6,240.00
5	Laxminagar	Head	2.50	139.81	79.5	2,544.00
6	Sukharampur	Head	4.30	188.32	219	7,008.00
7	Sandawa	Head	0.40	119.47	13	416.00
8	Mohoriya	Middle	0.13	32.22	37	1,184.00
9	Lamtiya	Middle	1.08	55.00	54	1,728.00
10	Bhander	Middle	0.62	56.00	68	2,176.00
11	Ganeshpur	Middle	1.98	55.00	82	2,624.00
12	Mahuwa	Middle	2.00	198.41	44	1,408.00
13	Dalpur	Middle	1.50	198.24	140	4,480.00
14	Hardihawa	Middle	1.90	253.05	125	4,000.00
15	Gotihawa	Tail	5.00	148.96	611	19,552.00
16	Shivapura	Tail	5.00	115.05	401	12,832.00
	Total		40.91	2,008.19	3,005.50	96,176.00

Notes: Length = Length of distributary canal and field channels maintained by WUGs in kilometers.

Total labor days = Number of person-days contributed by each WUG in maintaining the canals and channels.

Total cost = Estimate based on district wage rate of NRs 32/day/person (US\$1.00 = NRs 42.00)

- 1) Farmer participation in O&M activities reduced O&M costs of DOI. This year alone, the farmers mobilized NRs. 96,176 for O&M activities in BIS (Table 9.1).
- 2) There was increased farmer participation in meetings with DIO regarding conflict management and the implementation of irrigation rules and regulations by WUGs. The implementation of WUG rules and regulations was reinforced by fines for their infraction by members (Table 9.2).
- 3) Being involved as partners in the irrigation activities of BIS and having invested their time, energy, money and labor, some farmers have begun to have a sense of ownership of the system.⁵⁰
- 4) There was increased farmer participation in water allocation and in the preparation of the water distribution schedule. This resulted in better distribution of water, particularly in the winter season (Figure 9.2 and Table 9.3).

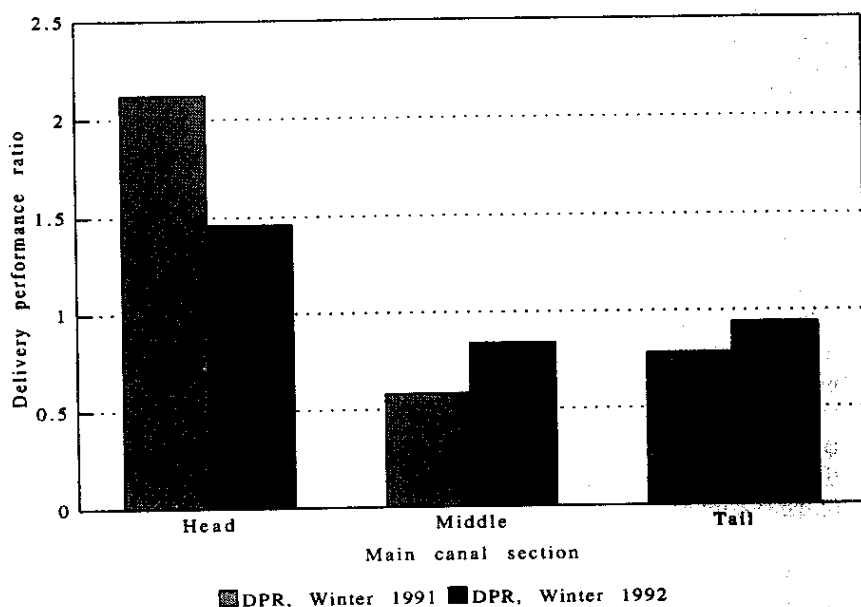
⁵⁰ Ownership of the system by farmers cannot be envisaged in the immediate future given the facts that the whole system will need to have water users' groups (preferably, confederated in one) and that the irrigation policy of the government has to address the ownership issue in the case of jointly managed irrigation systems.

Table 9.2. Collection of fines by water users' groups (WUGs), monsoon season, 1991.

Name of WUG	(1) Fines for absence at maintenance work (NRs)	(2) Fines imposed for grazing (NRs)	(3) Fines for absence at meetings (NRs)	Total (NRs)
Laxminagar		340		340
Gobari	390		25	415
Tilaura		315		315
Bilaspur	150	100		250
Gotihawa	120	115		235
Shivapura	275	75		350
Shukranpur	200	200		400
Total	1,135.00	1,145.00	25.00	2,305.00

Notes: 1. Fines imposed for being absent during group work in canal maintenance.
 2. Fines imposed on owner of livestock which were found free-grazing.
 3. Fines imposed on committee members for not attending committee meetings.

Figure 9.2. Delivery performance ratios for winter seasons, 1991 and 1992.



DPR=Delivery Performance Ratio
(Actual/Plan)

Table 9.3. Summary of irrigation delivery days as planned and observed (actual) and delivery performance ratios (DPR) for the head, middle and tail sections of the Banganga Irrigation System, winter seasons, 1991 and 1992.

Main canal section	Winter 1991		DPR	Winter 1992		DPR
	Planned	Actual		Planned	Actual	
Head	24 (25)	50 (52)	2.08	13 (24)	19 (34)	1.46
Middle	48 (50)	27 (28)	0.56	25 (45)	21 (38)	0.84
Tail	24 (25)	19 (20)	0.79	17 (31)	16 (28)	0.94
Total	96 (100)	96 (100)		55 (100)	56 (100)	

Notes. 1. The values in brackets are the ratios of irrigation delivery days to the total, in percent
 2. DPR = Delivery Performance Ratio: Actual/Planned.

Table 9.4. Introduction of crop diversification in the Banganga Irrigation System, winter season, 1992.

Village	Maize		Early rice		Onion		Sugarcane		Banana		Total	
	No. of households	Area in ha	No. of households	Area in ha	No. of households	Area in ha	No. of households	Area in ha	No. of households	Area in ha	No. of households	Area in ha
Bilaspur	18	1.47	6	1.58					1	0.03	25	3.08
Gobari	10	1.64	8	1.48					3	0.35	21	3.47
Semari	4	0.31									4	0.31
Tilaura	2	0.21									2	0.21
Sukhrampur	3	0.21									3	0.21
Laxminagar	4	0.31									4	0.31
Lamtiha							16	4.27	4	0.56	20	4.83
Shivpura					46	2.73					46	2.73
Total	41	4.15	14	3.06	46	2.73	16	4.27	8	0.94	125	15.15

- 5) There was a gradual introduction of early rice and crop diversification with the farmers having a sense of confidence in WUGs regarding the acquisition of water and its distribution as well as in safeguarding the crops from free-grazing cattle (Table 9.4).

Overall, the major achievements of this project are: the strengthening of the thirteen water users' groups in BIS and the transformation and sensitization of the BIS/DOI staff, in particular the BIS system manager. The farmer-to-farmer training method for effective organization was also demonstrated. DOI-farmer dialogue was enhanced through the frequent meetings that the BIS system manager has undertaken.

CONCLUSION

This paper began with the policy and legal contexts of participatory management and proceeded to deal briefly with IIMI's experience in facilitating farmer participation in irrigation management of a large Terai irrigation system in Nepal. Working within the constraints of both agency and farmer behavior, the involvement brought forth certain issues that may have general applicability towards the promotion of farmer empowerment such that they are actually partners of irrigation management with the agency.

The experience gained in this project leads us to several concerns and the rethinking to be done in terms of the process to be adopted during joint or participatory management and the extent to which rights are guaranteed to WUAs in such endeavors. In joint or participatory management, it would be important to address issues relating to farmer/agency partnership regarding power, authority, rights, responsibilities, sharing of activities, duties, mutual trust and accountability. It would be important for any government to strive for a true partnership taking into account the strengths, weaknesses, and the potential of partners with real ownership powers and the associated rights. This is in contrast to "partners" who are really beneficiaries and "ownership" which is only a sense of ownership.

It is true that a series of legitimate reasons can be voiced in favor of participatory management in Nepal. These reasons relate to reducing costs, enhancing performance, enhancing agricultural productivity, the agency shifting into newer roles and spreading itself too thin, etc. The question of the need for participatory management can be posed this way too: Is participatory management being promoted because of fiscal crises and the inability of the government to shoulder all the administrative, financial, and logistical burdens of irrigation management and expansion, or is it because of a genuine interest in partnership and support of local initiatives? This can also be viewed from the aspect of resource mobilization crises and the legitimacy crisis: Is the government willing to support rather than supplant local initiatives thereby not only augmenting its resource mobilization but also, in the very process, sharing power with the local users, now partners, by empowering them to control resources that affect their own lives and thus gaining legitimacy in the eyes of the public? Thus, as farmers become involved in the management of their "own" resources, they have more control over their own lives, both economically and socially. Shared, participatory irrigation management has the potential for improving both agricultural production and social well-being.

Specific results or outcomes were also described whereby the process performance contributed, although in an indirect manner, to the output performance. With the organization of thirteen water users' groups, a significant contribution was made in terms of labor for canal maintenance. Better relations and communications with the Banganga Irrigation System staff were fostered. Reductions in water-related conflicts and destruction of water control facilities were observed. More participation of farmers in main system management was also attained. All of these contributed to the more equitable distribution of irrigation water, particularly in the winter season.

Thus, despite the limited period for undertaking this action-research project, the foregoing results and emanating issues are considered significant contributions to a better understanding of the process in organizing farmers and their implicit effects on output performance..

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CHAPTER 10

Performance of Chashma Right Bank Canal: Technical and Economic Indicators in the Context of Crop-Based Irrigation Operations

Pierre Strosser and Carlos Garces

INTRODUCTION

POPULATION PRESSURE COUPLED with watershed deforestation, secondary salinization, waterlogging and crop yield stagnation are some of the serious issues being faced by the irrigated agriculture sector in Pakistan. This state of affairs has led the Government of Pakistan to search for fresh and innovative ideas on how to improve the performance of irrigation systems and on how to assure their sustainability.

The introduction of crop-based irrigation operations into traditional supply-side irrigation schemes is one of the mechanisms through which the government would like to see a radical departure from longstanding practices.

The construction of a new irrigation system, the Chashma Right Bank Canal (CRBC) and the remodeling of an existing one, the Lower Swat Canal, both in the North-West Frontier Province, provided an excellent opportunity for the provincial government to try out the concept of seeking a better match between the supply and demand of scarce water resources. This approach, referred to as crop-based irrigation operations, was a part of the project plans, but difficulties were encountered in its implementation. Since July 1991, the International Irrigation Management Institute (IIMI) is implementing, in collaboration with concerned local agencies and through funding from the Asian Development Bank, a three-year project to attempt to understand and identify ways of overcoming these problems.

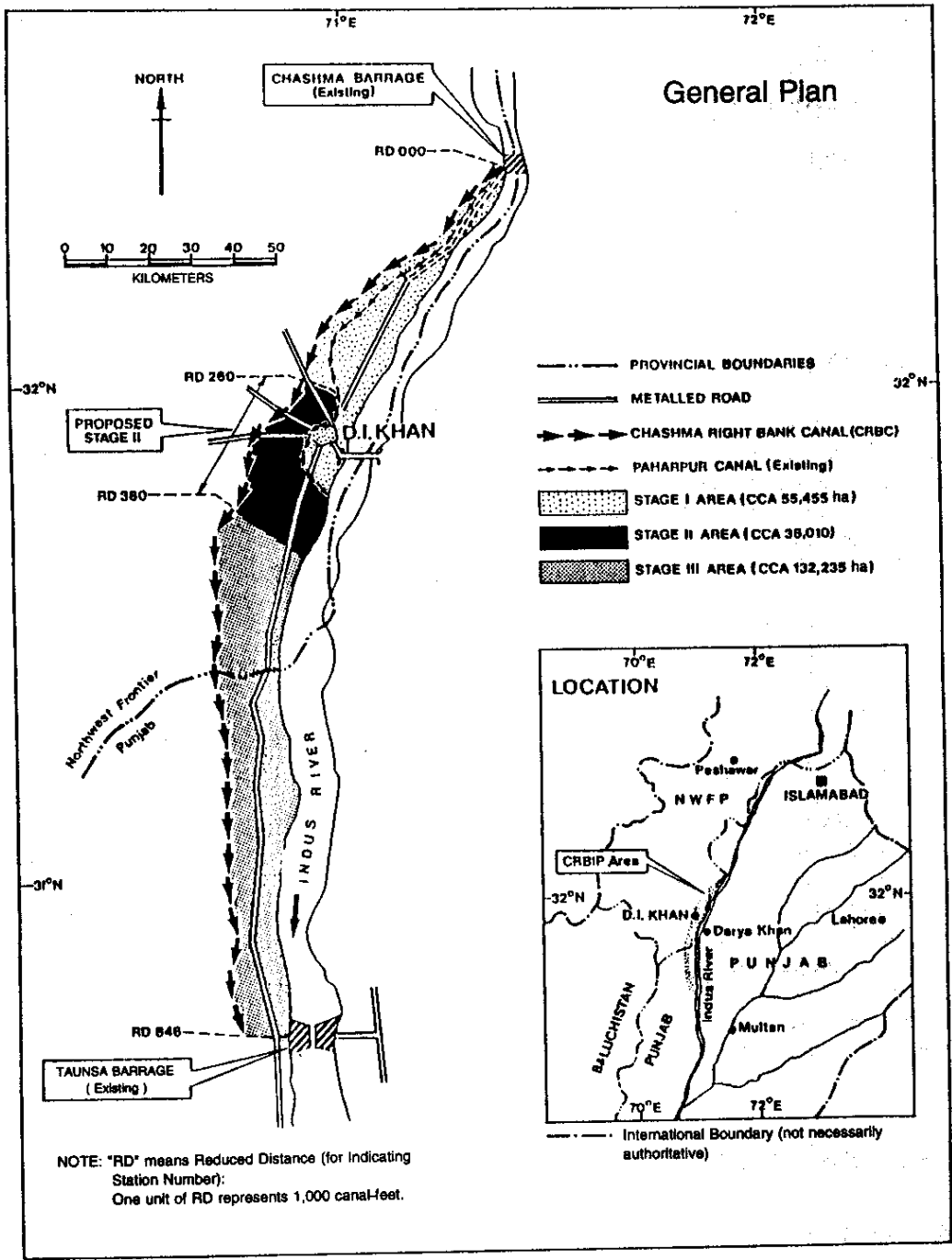
This paper relates some of the constraints encountered during the first year of activities and sets forward a series of performance indicators being utilized in the context of crop-based irrigations but with the caveat that the system continues to operate in the traditional supply-based approach. Wherever possible, performance guidelines proposed by members of IIMI's Performance Task Force (see Murray-Rust 1992) have been followed in order to pursue standardization of concepts throughout the Institute.

THE CRBC IRRIGATION SYSTEM

The Project

The Chashma Right Bank Irrigation Project (CRBIP) will create a major perennial surface irrigation system that, once completed, will cover a gross command area of about 280,000 ha of

Figure 10.1. General plan and location of Chashma Right Bank Irrigation Project (CRBIP).



land on the right bank of the Indus River in Central Pakistan, stretching between Chashma and Taunsa barrages (see Figure 10.1).

The main source of water for the system is the Indus River by means of the Chashma Barrage which was commissioned in 1982. The main canal is 285 km long with a culturable command area (CCA) of 230,675 ha that spans two provinces, the North-West Frontier and Punjab, in a 60 to 40 percent proportion, respectively.

Because of the magnitude of the project, construction of the main canal and the distributaries has been subdivided into three stages. Stage I runs for 79 km (RD 000 to RD 260) and covers a CCA of 56,600 ha, Stage II runs for 37 km (RD 260 to RD 380) with a CCA of 36,240 ha and Stage III runs for 142 km (RD 380 to RD 846) with a CCA of 137,835 ha (one unit of RD represents 1,000 canal-feet).

Construction of Stage I has been completed and the system became operational in early 1987; it includes the old Paharpur Irrigation System which has been remodeled for increased capacity and is now being fed by the CRBC through 4 link channels. The full capacity of 138 cumecs of the main canal, to be distributed through 49 distributaries and 4 link canals, is not likely to be utilized for the remainder of the century upon completion of Stages II (which is in an advance stage of construction, with completion scheduled for mid-1993) and III (construction scheduled to begin in 1993).

The total cost of the project has been pegged at Rs 10,213 million (WAPDA 1991). The project represents the newest system in the country and the largest undertaken to date in the North-West Frontier Province. It is looked upon as a model for future irrigation-expansion-related activities. The main features of the CRBC Irrigation System are summarized in Table 10.1.

Water Distribution at Main-Canal and Secondary-System Levels

The system faces the dichotomy of having been designed in a **supply-based** delivery approach, which is long rooted in the country's irrigation community, while the desire is to operate it in a **crop-based** approach. While the former is being exercised through an administrative system, the latter requires that the process of water distribution be managed. The degree of success expected in operating the system will depend on the extent to which these two different approaches can be reconciled.

For example, designed water deliveries at the main-canal level were calculated on the basis of a 10-day total crop water requirement (losses included) and they vary from a minimum of 40 cumecs to a maximum of 137 cumecs. The distributaries, on the other hand, following traditional supply-based irrigation as advocated by the agency, should run no lower than at 70 percent of their full supply level (FSL). In the main canal, it is possible to achieve the required water elevations by means of existing cross-regulators, escapes and gated offtakes,⁵¹ but, comparable operational flexibility is not found at the distributary level.

The above issue is further clouded when no decision at the highest provincial and/or federal level exists on how flows are to be diverted into the CRBC through continuous peak-requirement flows, with the excess flows returned to the river by means of existing escapes or by varying discharges according to total crop water requirements. The final decision will certainly have an impact on how the system is to be operated.

⁵¹ This particular issue of whether the existing main canal infrastructure is sufficient to cope with varying flows is also being studied by IIMI under the Decision Support System sub-component of the Cooperative Agreement Project. See, for example Habib, Z. et al. (1992).

Table 10.1. Main Features of the CRBC Irrigation System.

Construction begun in	: 1986
Supply sources	: Indus and Kabul rivers
Source regulation	: Chashma Barrage
Type of system	: Gravity flow
Average water allowance	: 0.60 lps/ha
Type of main canal	: RD* 000 to RD 097 unlined; RD 097 to end lined.
Length of canal network	: 603.37 km
Type of outlets	: Pipe
Drainage system	: Tile drains in selected areas of Stage I

	Stage I	Stage II	Stage III	Total
Design discharge (cumecs)	34.73	22.63	80.72	138.07
Length of main canal (km)	87.88	40.56	157.17	285.6
No. of distributaries	5 + (4 links)	8	36	53
CCA (ha)	57,605	35,547	135,523	230,675

	Kharif	Rabi	Total
Designed cropping intensity (%)	60	90	150

* One unit of RD ("Reduced Distance") represents 1,000 canal-feet.

At present, however, project monitoring activities clearly indicate that the water supply being provided to Stage I of the CRBIP exceeds crop water requirements; but, there is considerable inequity in the distribution of water, despite the excess, with those areas at the tails of the command receiving less. The excess water supply, notwithstanding the conditions at some tail reaches of watercourses, has created a sense of abundance of the resource among water users. Clearly, as more and more land is brought under irrigation, the system will necessarily have to reduce water supplies in Stage I creating conflict with the users already accustomed to overdeliveries.

A final comment that can be made in this section relates to the state of flux that still prevails in the development of the system as a whole. While the area under irrigation in Stage I has been, for the most part, consolidated, Stage II is continuously bringing new land into irrigated conditions as construction advances. That changing situation has deterred the operating agencies (Water and Power Development Authority [WAPDA] at main-canal level and the provincial Irrigation Department [ID] at distributary level) from taking firm operational decisions because these may no longer be relevant in a short time. Thus, the government institutions are reluctant to try any bold initiatives at this point in time.

Water Management below the Outlet

Influential farmers appear to be the main individuals who decide on the distribution of water at the watercourse level. Very few formal requests for an official allocation of water among irrigators have been made to the Irrigation Department. In most of the watercourses, water is allocated through an unofficial *warabandi* (fixation [*bandi*] of turns [*wara*]) with a 7-day rotation.

The *warabandi* system, however, is not always followed by farmers. First, exchange of turns seems to be a rather common practice to increase the flexibility of the *warabandi* (unofficial or official). This is the case especially for the head-end farmers of the watercourses. Second, differences in water distribution exist between seasons. Farmers are much less concerned by their water turns during the rabi season, with the water supply exceeding the demand by a vast amount. They share their irrigation water turns (for example, up to 6 farmers from the same watercourse have been reported to irrigate at the same time during the last rabi season of 1991/92) or they close their outlets when water is not needed. During the kharif season, they tend to follow their *warabandi* more closely.

Even if water is in excess at system level, differences are found when comparing watercourses and farmers. Water availability and the management of water, for example, are major concerns of farmers located in the tail reaches where water is scarce. Some of these farmers even purchase water from other farmers in order to have a sufficient irrigation water supply.

Most of the Water Users' Associations organized by the On-Farm Water Management Department at the time of the lining of the watercourses have ceased to exist or do not function anymore. Farmers cooperate to maintain their watercourses, but this cooperation remains limited. They rarely intervene jointly in the management of water above the outlet, except in extreme cases like the tail-end farmers from watercourses of Distributaries 3 and 4, who have been able to organize themselves to influence the operating agencies to build a specific minor (Jabbar Wala Minor) to irrigate their lands.

Farming Systems and Agricultural Production

Nearly all the farmers of the command area of Stage I had experienced irrigated agriculture before the commissioning of the CRBC. However, these experiences were gained mainly in tubewell (public or private) irrigation or canal irrigation with much smaller water flows than the ones delivered by the CRBC. Farmers and their farming systems are still in a transition phase, the farmers trying to incorporate the high water duties specific to this new irrigation environment.

The importance of rice (around 20% of the CCA) and the emergence of sugarcane (although still occupying a relatively small percentage of the CCA) are indicators of the impact of the new water supplies on the cropping patterns and the farming systems. However, farmers remain highly rabi-oriented, the percentage of fallow land being much higher during the kharif season (40% of the CCA) than during the rabi season (10% of the CCA). The migration of a part of the population to the hilly areas at the beginning of the hot season, leaving some land fallow during the kharif season, is one factor that explains this rabi orientation. Another one could be the current irrigation water supply which seems to be relatively more scarce during the kharif season.

Forty to fifty percent of the CCA is cultivated to wheat and around 20 percent of the CCA is under gram (a type of pulse). The importance of gram, rarely irrigated, is explained by the position of this crop in the wheat-rice-gram-rice rotation and by the fact that farmers are not yet fully adapted to the higher irrigation water duties of the CRBC system. The other crops grown are fodder (rabi and kharif seasons), maize and some vegetables and oilseeds.

The average farm size is 12.5 ha (average of data from 318 farms of distributaries 3 and 4), 90 percent being irrigated land. However, more than 50 percent of the farmers cultivate less than 5 ha of land each. Differences in the farming systems exist within the command area of Stage I. The areas supplied by Distributary 1 are not yet fully developed with a substantial percentage of fallow land; in distributary 3, the cropping pattern is more diversified than in the rest of the system; farmers from Distributary 4 are more oriented to raising livestock (mainly goats and sheep), certainly due to the fact that many of the farmers from this distributary are recent settlers including migrant tribes from Afghanistan.

The main constraints on agricultural production reported by farmers are related to land development (fields too high or not leveled), irrigation water supply (as reported in the previous section) and lack of credit to buy the necessary inputs (seeds, fertilizers), machines (tractors) or to develop their land. The last aspect, credit, is seen as especially important for some farmers having invested large amounts of money in the purchase of expensive newly irrigated land. They find themselves without enough money to develop this land or to buy inputs for a cropping season.

PERFORMANCE INDICATORS FOR CROP-BASED IRRIGATION

The main objectives of this part is to define and discuss a set of performance indicators to be used in a crop-based irrigation context. The different aspects taken into account in the selection of appropriate indicators for the performance assessment of the system are primarily the objectives of crop-based irrigation themselves and also some characteristics of the studied irrigation system, Chashma Right Bank Canal.

Objectives of Crop-Based Irrigation

The primary objective of Crop-Based Irrigation is :

to increase the utility of land by supplying water to a specified system according to crop water requirements.

Adequacy and timeliness are two important components of such a supply leading to the necessity to have a flexible supply system, flexible not only over time (to respond to changes in the irrigation water requirements due to changes in crop needs or rainfall) but also over space (to distribute different quantities of water to different parts of the system according to specific needs).

What is meant by "system" here is the irrigated agriculture of a delimited area, in this case the command area of the CRBC. It includes not only the water distribution system per se but also the farming system with its different characteristics in terms of inputs used, transformations undertaken and outputs produced (in the following sections, for example, the output of the system will be related to agricultural production).

The definition of the type of performance to be considered is the first step of the analysis of the performance of an irrigation system. Three different views of performance (Murray-Rust 1992) are chosen to frame the discussion:

1. **Objective-setting performance:** to evaluate the relevance and feasibility of objective(s) selected for the operation of an irrigation system.

2. **Operational performance:** to compare the actual operation of the system with a defined set of targets.
3. **Output performance:** to evaluate the impact of the operation and management of an irrigation system on agricultural production.

It has to be emphasized that these three views are complementary and interrelated. The choice of feasible targets for the operation of the system, for example, will be evaluated in the objective-setting performance analysis.

In a second step, the level of focus has to be clearly defined. Although general objectives are set for an irrigation system, it is useful to understand what is meant in terms of objectives at different levels of the irrigation system (main canal, distributary, watercourse, farm, field). Following the same line, targets for operational performance are expected to vary from one level of the irrigation system to the other. Different individuals or groups are involved in the operation and the control of the water flows at each level and they are responsible for its performance. Finally, the output will be evaluated and more or less aggregated according to specific needs (study of yields at farm level or analysis of the capacity of agricultural production of the system, etc).

Suggested Performance Indicators

Objective setting performance. Three aspects have been identified as having greater importance within a crop-based irrigation environment.

The first one is related to water resources and the **availability of water for irrigation**. The question whether there is enough irrigation water to match water requirements of the crops of the area has to be answered clearly. This issue will be addressed by the calculation of the Allocation Adequacy Indicator, defined as the arithmetic mean of the relative differences between the water allocated and the water required (in absolute values) measured daily for 10 days.

The comparison between the flows in the Indus River at Chashma Barrage and the flows required for the CRBC shows that the quantity of water available in the Indus River is not a limiting factor at all. More important than the flows passing through Chashma Barrage, however, is the amount that has been (or will be) allocated to the CRBC Irrigation System.

Although it is stated in the Loan Agreement between the Asian Development Bank and the Government of Pakistan⁵² that

...CRBIP will have a maximum withdrawal rate of 5,000 cfs from the Chashma Barrage at the Indus River ... available at any time of the year...

it is difficult to estimate, at present, the amount of water that will be allocated in the future within the context of the recent Water Treaty and negotiations between the 4 Provinces of Pakistan for the allocation of the water resources of the country.⁵³

The second question to be addressed is **whether the CRBC Irrigation System can be operated as a crop-based irrigation system**. Has the system been designed in such a way that water can be distributed according to the crop water requirements? This approach is more technical

⁵² Para 4, Schedule 6, Loan Agreement No. 330, Chashma Right Bank Irrigation, approved 15 December 1977.

⁵³ This problem of allocation is already playing a role in the delays occurring in the design and construction of Stage III of the CRBC (approximately 80% of which is located in the Punjab Province while Stage I and Stage II are located entirely within the North-West Frontier Province).

and has to consider not only the installed infrastructures and the possibilities of water control at different points of the main and secondary canals but also some hydraulic parameters as velocity or sedimentation rate, important in a proper longer-term evaluation of the constraints and limitations of the physical system.

The Physical System Adequacy is the indicator used to evaluate the adequacy of the physical system, calculated as the percentage of time the objectives of crop-based irrigation could be met. It will be calculated as the ratio of the number of 10-day periods of a year the objectives could be met divided by the total number of 10-day periods in a year.

The third (last) aspect has to do with the operation of the system itself : **are the operators able to operate the system in a crop-based irrigation mode ?** The financial resources of the operating groups (farmers included), the personnel needed to operate the system in a proper manner, or the information system needed for a proper flow of information between agencies and farmers are important components to be considered within this last aspect.

This issue has not been addressed in this paper. However, the comparison between what is needed for the operation under crop-based considerations and what is available is a simple way, in principle, to estimate this third aspect, expressed as a percentage ("funds available/costs of the operation of the system" or "personnel available/personnel needed for crop-based irrigation operation").

Operational performance. The adequacy of water supplied in relation to the water requirements of an irrigation scheme is the main objective of crop-based irrigation. The Relative Water Supply (RWS), the ratio of the supply to the demand (Levine 1982), appears to be an appropriate indicator to assess this adequacy. However, although this indicator appears to be relatively simple, a set of questions related to the definition of supply and demand, levels at which RWS has to be calculated, targets for RWS, etc., has to be addressed carefully.

Using field water requirements as demand and setting realistic targets for the various levels of the system is the approach recommended by Bird et al. (1992) and it has been used in this paper. The 10-day RWS is the basic indicator calculated at main-canal, distributary and watercourse levels. For each 10-day period, the RWS is calculated as presented below:

$$\text{RWS} = \frac{\text{Irrigation} + \text{Effective Rainfall}}{\text{Crop Water Requirements} + \text{Seepage and Percolation}}$$

Due to the impossibility of collecting irrigation application data for sample farms in the CRBC area, it is not possible to calculate the RWS at farm level, which is necessary for the analysis of the variability of this indicator in the farm population.

Four different indicators (based on 10-day RWS and the amount by which it differs from the target supply over time) have been chosen for the evaluation of the operational performance at different levels of the CRBC Irrigation System. The first two indicators are related to the adequacy of the supply and are:

- **The Seasonal Adequacy Indicator.** This indicator is an estimate of the relative difference of the RWS to the target⁵⁴ for each location and period of time and its arithmetic mean is used to calculate the value of the indicator for a given period of time (in this case, a

⁵⁴ Target values to be used at different levels of the system are respectively 1.38, 1.45 and 1.55 for watercourse, distributary and main-canal levels, based on estimates of conveyance losses at watercourse, distributary and main-canal levels.

season). It is an estimate of the adequacy of the total supply of irrigation water for a season, assuming that an oversupply during a period of time can be used during the next under-supplied period.

- *The Supply Inadequacy Indicator* is the same relative difference as above but when the target supply is greater than the RWS (negative values of this difference). As the basic Molden and Gates Adequacy Indicator (Molden and Gates 1990), it indicates undersupply which could lead to crop stress and yield reduction.

The other two indicators selected, which are more oriented towards the operator itself, are:

- *The Supply Mismatch Indicator*, an evaluation of the performance of the operators themselves, is the average over the season of the difference between the actual operation and specific targets (varying over time) in absolute values.
- *The Equity Indicator* is the average of the spatial coefficients of variation of the RWS, which is an evaluation of the discrepancies among locations of the CRBC Irrigation System.

The four indicators are compared to zero, which represents the ideal crop-based irrigation operations. The indicators calculated in current conditions represent the deviation in terms of percentage from the target value, an estimation of the discrepancy between crop-based irrigation operations and current operations of the system.

Output performance. Different aspects of the farming system have to be considered in the analysis of the impact of the irrigation water supply on the agricultural production: cropped area, cropping pattern, yields or inputs used, etc. In order to aggregate the different aspects of the farming system, the weighted gross margin per unit of land is used as an economic indicator.

This average gross margin is ultimately calculated for different watercourses and distributaries.⁵⁵ Its spatial coefficient of variation is also calculated to estimate an economic equity among different locations of the present irrigation system.

The analysis of the different components of this indicator, however, is still needed in order to understand the decision-making process of the farmers. Cropping intensity, cropping pattern, yields and gross margins for specific crops are analyzed and compared to design values (for cropping intensity and cropping pattern) or values available from other sources.

In this paper, cropping intensity and cropping pattern at a watercourse level are evaluated against design values. Yields per unit of land (kilogram per hectare) and gross margin per unit of land (rupees per hectare) for the wheat crop only are computed and compared to available secondary data.⁵⁶ Moreover these will serve as benchmark values for IIMI's work in the area.

⁵⁵ Similar indicators could be calculated using the energy content of a kilogram of each crop product or using wheat equivalent values as described by Carruthers et al. (1983).

⁵⁶ For the next seasons, data will be collected for other main crops and the weighted gross margin per ha computed.

IIMI's Crop-Based Irrigation Operation (CBIO) Project: Some Comments

The previous discussion has been based on crop-based irrigation considerations only, without including other objectives or constraints of the CRBC Irrigation System. Although IIMI's Crop-Based Irrigation Operation Project in the North-West Frontier Province (NWFP) is mainly oriented towards crop-based irrigation, one of its many objectives is:

to improve the overall productivity of water resources within the authorized water allocations and subject to the available supplies.

This is not an explicit objective for the operation of the CRBC Irrigation System. But given the scarcity of the water resources in the country, it is an implicit one. The weighted gross margin per unit of water will be the other output performance indicator to be compared with available secondary data and to assess changes in productivity. The monitoring of the productivity of water, however, has a real meaning only if water saved within the CRBC is used somewhere else downstream along the Indus River.

The problem of water allocation is raised here, leaving open the possibility of crop-based irrigation operations within a water-scarce environment (by water-scarce it is meant that enough water is not available for the crops planted by the farmers of the area). Although water is in excess in the current situation, new land developments, changes in cropping intensities and cropping patterns are expected. Moreover, Stage II and Stage III of the CRBC will become functional and draw a part of the available water supply. If water is scarce, the primary operational objective becomes equity and the minimization of the spatial coefficient of variation of the RWS.

Some of the constraints of the CRBC Irrigation System operation have to be taken into account when defining the targets for the operation of the system. The need to close the canal for maintenance during a certain period of the year is one of these constraints. The target for the operating agencies during this period is not to match the irrigation water supply to the crop irrigation requirements anymore but to deliver no water. Out of all the indicators described and selected, only the Supply Mismatch Indicator has to be modified accordingly.

Table 10.2. Performance indicators for the CRBC Crop-Based Irrigation Operation Project.

Performance	Indicator	Target
Objective setting	* Allocation Adequacy	0
	* Physical System Adequacy	100%
	* Personnel (or Financial) Availability Ratio (in %)	100%
Operation	* Seasonal Adequacy	0
	* Supply Inadequacy	0
	* Supply Mismatch	0
	* Equity	0
Output	* Weighted gross margin (per unit of land and per unit of water)	Compared to secondary data
	* Cropping intensity	Design
	* Cropping pattern	Design
	* Crop yield and gross margin per unit of land	Compared to secondary data
	* Crop yield and gross margin per unit of water	Compared to secondary data

Summary of Performance Indicators

To address issues related to objective-setting performance, operational performance and output performance, a set of indicators has been selected. These indicators are presented in Table 10.2, along with their target values. Their mathematical formulae are described in the Appendix.

APPLICATION OF INDICATORS TO THE CRBC, RABI 1991/92 SEASON

Methodology and Data Collection

The first objective of IIMI's project in the CRBC area has been to analyze the current operation of the irrigation system and to assess its level of performance (operational performance and output performance). To calculate the different indicators proposed in the previous section of this paper, a large set of data (primary and secondary) has to be collected. At the main-canal level, the core of data which has been used is secondary data (collected by WAPDA). Primary data collected by IIMI field team are increasingly important while addressing issues at smaller irrigation units (distributary, watercourse, farm and field levels). Table 10.3 summarizes the main components of the primary data set collected during the first rabi season.

Table 10.3. IIMI Data Collection Program, the CRBC, rabi, 1991/92.

Study	Component	Field activity	Main canal	Distributary	Watercourse/ Farm
Irrigation system operation	Simulation Water management	Canal monitoring Interviews, Warabandi	XXX —	XXX XXX	— XXX
Supply and demand of irrigation water	Water supply Water losses Crop requirements	Flow measurements Maps, crop survey	— — —	XXX XXX —	XXX XXX XXX
Irrigation institutions	Role of agencies Role of farmers	Officials' interviews Farmers' interviews	XXX —	XXX XXX	XXX XXX
Economics of the CBIO	Farming practices Agricultural input/output	Survey (contractor) and regular monitoring	— —	— —	XXX XXX
Others	Social environment Meteorology	Survey (contractor) Rainfall, Evaporation	— XXX	— —	XXX —

Note: XXX denotes that the data in a row were collected at the level in the corresponding column.

Two distributaries (Distributary 3 and Distributary 4) have been monitored since November 1991. In each distributary, 8 watercourses have been selected, 2 in each quartile of the distributary command area. Because of the integration of the Paharpur Canal Irrigation System into the CRBC Irrigation System, Girsal Minor, continuation of Distributary 3 in Paharpur command area, has been included in the regular monitoring as well. In four watercourses from Distributary 3, six

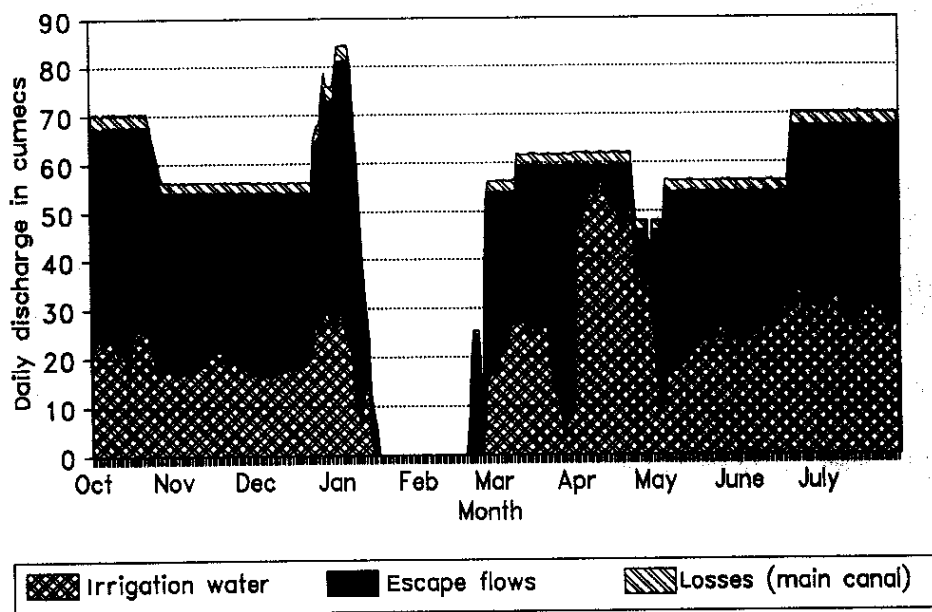
sample farmers have been monitored regularly to gain a better understanding of their farming practices and water management at farm level.

The present study focuses on the operation of the main canal and one distributary, Distributary 3, and its watercourses. For this distributary, management changes at a secondary and tertiary level were tested ultimately. Distributary 4 was used as a control and its performances was compared to the performance of Distributary 3 with improved irrigation operations. Most of the data cover the 1991/92 rabi season period. To understand the operation of the system, however, data on the water supply up to June–July, 1992 were also used.

Current System Operation and Operational Performance

The discharge of the water released from the Chashma Barrage at the head of the CRBC is fairly constant for a season. WAPDA data reveal that the discharge for rabi 1991/92 (between November 1991 and April 1992) has, most of the time, been equal to 55 cumecs, varying from 48 cumecs to 60 cumecs. For the kharif season (end of kharif 1991 and beginning of kharif 1992), the discharge is equally constant and close to 70 cumecs (see Figure 10.2).

Figure 10.2. Discharge of water from the CRBC: Irrigation, escape flows and losses.



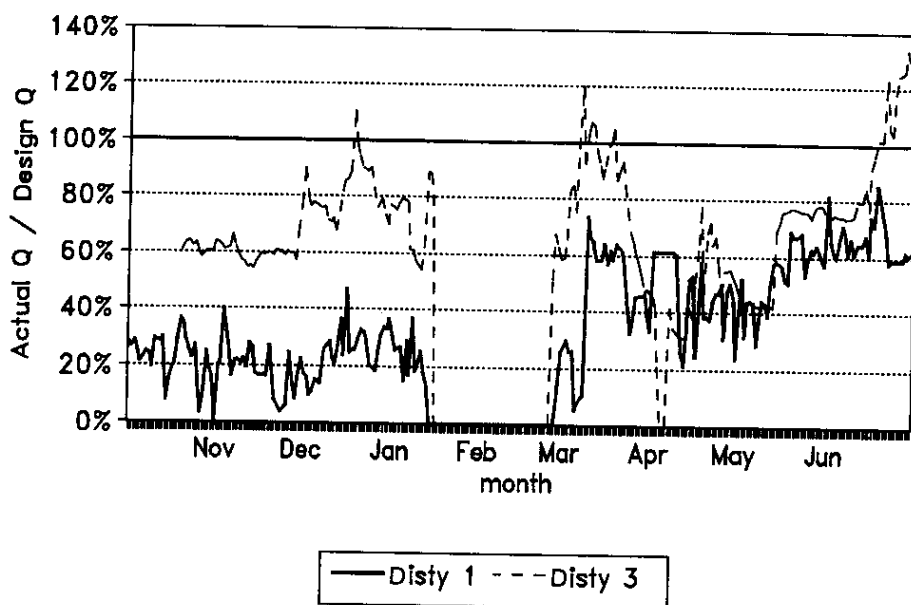
For two periods, however, the discharge of the head of the CRBC has been different. No water has been released into the canal from January 15 to February 25, 1992, for the maintenance of the irrigation water supply network. This canal-closure period was first supposed to take place from the 1st of January to the 31st of January. However, it started only on January 15 for technical reasons related to the Chashma Barrage operation and lasted 10 days more than planned because

some structures had to be repaired at distributary level. The discharge of the two weeks before the canal closure, on the contrary, is rather high. The peak is related to repairs and/or maintenance work at the barrage; the CRBC canal was used as an escape to facilitate the work.

Figure 10.2 also highlights the discrepancy between the amount of water released at the head of the CRBC and the amount used for irrigation. It shows that the supply at the head does not follow recorded changes in irrigation water. Both are quite similar for one period only (April 1992). This, however, is mainly due to the way WAPDA records the amount of water for irrigation,⁵⁷ which does not represent what is effectively used for irrigation by farmers. For most of the time, the discrepancy between the volume of water released at the head and the volume of water used for irrigation is due to the widespread use of the escapes (in fact, mainly, the escape at the end of Stage I) at main-canal level.

The four distributaries monitored by IIMI during the same period do not follow the same trend as the main canal as could be suspected by looking at the changes in the volume of irrigation water reported by WAPDA. The discharges recorded by WAPDA are much more variable as shown in Figure 10.3, which presents the ratio of the actual discharge to the design discharge,⁵⁸ recorded daily from October 1991 to June 1992 for Distributary 1 and Distributary 3.

Figure 10.3. Ratio of actual discharge to design discharge: Distributaries 1 and 3 of the CRBC, October 1991 to June 1992.



⁵⁷ During April 1992, repairs were made at the escape structure at the end of Stage I. A part of the extra water flowing in the canal has escaped into Stage II. This water, although not used for irrigation, is recorded as irrigation water following WAPDA data collection formats.

⁵⁸ What is defined here as the design discharge is the value used to calculate the required capacity of the different distributaries to carry the maximum discharge during the peak crop water requirement period. It is not an operational target discharge.

For the period March to June, the four distributaries follow a similar trend, with, first, a decrease in the daily water supplied to the distributaries (at the wheat harvesting time) followed by a marked increase starting in May, the beginning of the kharif season with higher irrigation water needs. It is interesting to note that the discharge at the head of the CRBC has also increased at the beginning of the kharif season but only one month later than the increase recorded at distributary level.

The comparison of the ratio of the daily discharge over design discharge with two threshold values, 100 percent of the design discharge and 70 percent of the design discharge (indicated by the Irrigation Department as the lower limit at which they could run the distributaries) leads to the following conclusions:

- The discharge of Distributary 1 is well below the 70 percent the threshold most of the time, due to the low level of development of the agricultural land in its command area.
- The discharge at Distributary 3 head varies from 50 percent to 100 percent of the design discharge during the rabi season. The trend for the beginning of the kharif season shows that much higher values will be attained.
- The discharge at the head of Distributary 4 is fairly constant and close to 70 percent of the design during the rabi season. The first values for the kharif season seem to predict a constant discharge for kharif but at a higher level, close to 100 percent of the design discharge.
- Distributary 2 discharge covers the largest range of discharges, from 20 percent to 120 percent during the rabi season and more than 150 percent at the beginning of the kharif season.

Moreover, the analysis of the monthly coefficient of variation of the discharge shows that the largest distributary and the one closest to the cross regulator at the end of Stage I, Distributary 4, has the lowest monthly coefficient of variation for every month. Most of the time, Distributary 3 has the highest coefficient of variation of the four distributaries of the group, except for March 1992 when Distributary 1 has the highest coefficient..

To understand the behavior and the operation of the distributaries, data collected in Distributary 3 has been used. The water supplied to Distributary 3 served three different areas: the area of Distributary 3 itself, the area commanded by Kech Minor taking off at the tail of Distributary 3, and the command area of Girsal Minor which is the continuation of Distributary 3 in the Paharpur Canal Irrigation system. From January to June 1992, water delivered at the head of the distributary has been much higher than the requirements of the distributary itself and Kech and Girsal Minors. The oversupply released to the downstream part of Paharpur Canal is represented in Figure 10.4 in comparison with the three other components of the Distributary 3 water supply.

The 8 sample watercourses monitored in Distributary 3 since October 1991 react differently to changes in the discharge at the head of the distributary. The average discharge into the watercourses varies from one watercourse to the other. Watercourse 6468-L, for example, has an Average Q/Design Q ratio of 1.2 against a value of only 0.65 for the last watercourse of the distributary, 15382-R. However, the analysis of the average discharge at a watercourse head is not sufficient to estimate the quantity of water used by irrigators. They can control the discharge by closing and opening their *moghas* at the distributary side or at the watercourse side. Data collected by IIMI from November 1991 to August 1992 highlight the extent of this practice, from one month

Figure 10.4. Water distribution below Distributary 3 head: Daily discharges in cumecs.

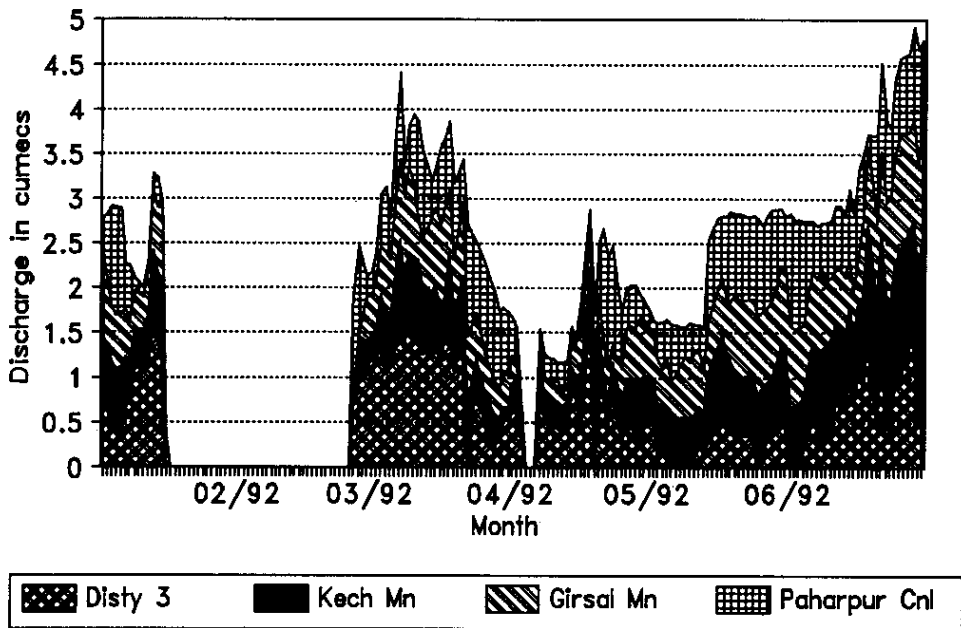
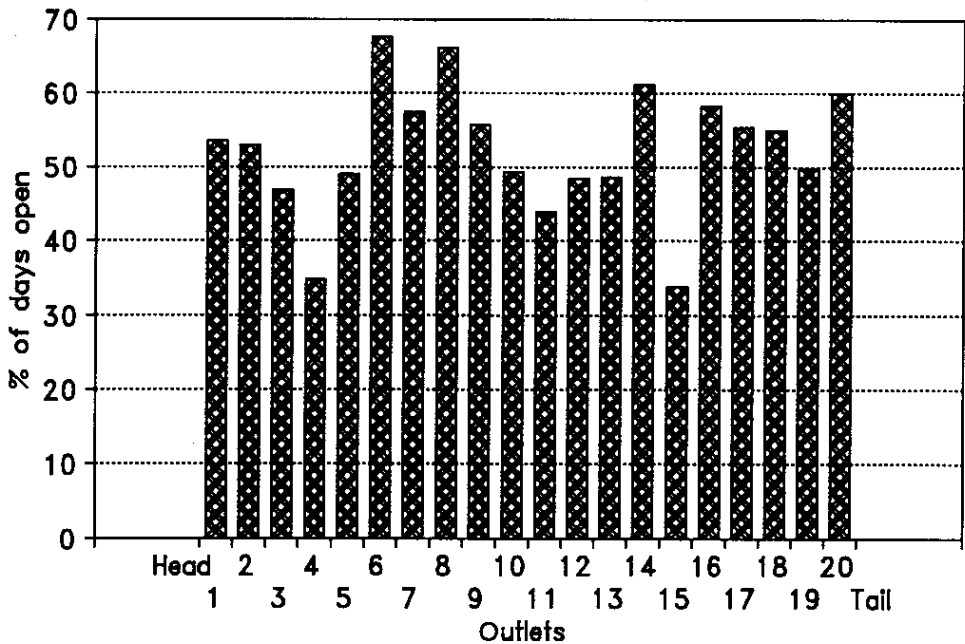


Figure 10.5. Duration (% of days) for which outlets are open: Distributary 3, CRBC (11/91 to 08/92).



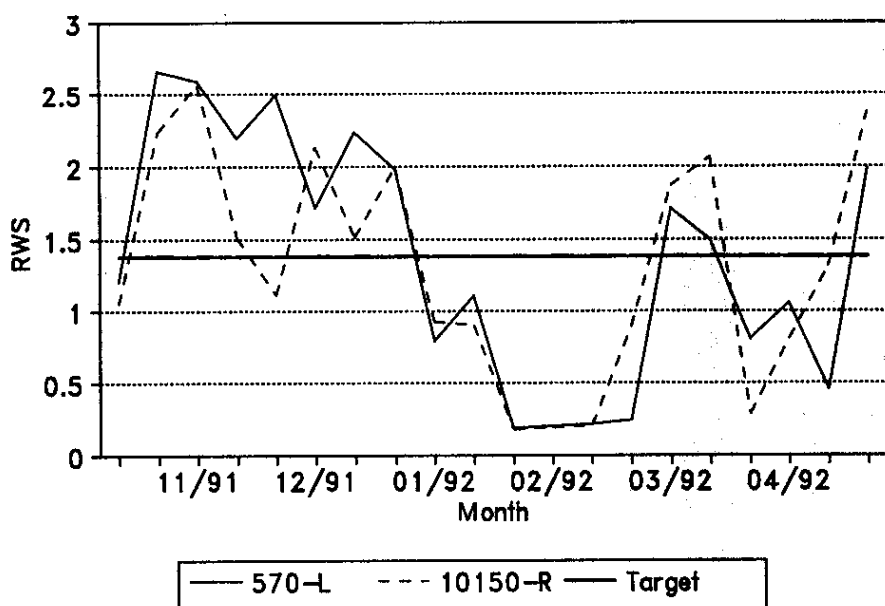
to the other, where outlets are closed by farmers from 30 percent (June 1992, at the time of rice transplanting) to 70 percent (April 1992, at the time of wheat harvesting) of the time.⁵⁹

The duration (% of days) for which outlets were open is shown in Figure 10.5. There is no relationship between the percentage of days the outlet is closed and the position of the outlet along the distributary, from the head to the tail. Moreover, the proximity of a drop structure, which may allow control of the water surface level in the distributary, does not have any impact on the percentage of days watercourses are open.

Using flow data presented above and the cropping pattern for 8 watercourses in Distributary 3 (see Impact on Agricultural Production on p. 263), the Relative Water Supply has been computed for each 10-day period of rabi 1991/92 at different levels of the irrigation system as discussed earlier under Performance Indicators for Crop-Based Irrigation (p. 252). At every level (the CRBC head, Distributary 3 head and heads of sample watercourses), the variation in the RWS has been quite significant over time.

Figure 10.6 highlights this temporal variation of the RWS for 2 sample watercourses monitored by IIMI. The cut in the irrigation water supply during the canal closure of January-February 1992 period is naturally expressed by a very low RWS for three periods of 10 days. For the whole season, three localized peaks are observed, corresponding mainly to the periods of pre-irrigation (end of October), first irrigation (December) and second irrigation (March) of the wheat crop, which is predominant in the current cropping pattern of the sample watercourses. Two of these three peaks surround the canal-closure period and thus partly compensate for the shortage of water during this 40-day-long period.

Figure 10.6. Variation of RWS of two sample watercourses, 570-L and 1015-R of Distributary 3, CRBC.



⁵⁹ Percentage of the time outlets are closed calculated as percentage of the days water was available in the distributary; thus it does not include the canal-closure period.

Based on the 10-day RWS, the main operational indicators described earlier have been calculated at different levels (watercourses of Distributary 3, Distributary 3 head and the CRBC main-canal head) and are presented in Table 10.4. For each of the indicators, the target is zero and calculated values represent the relative deviation from the target.

Figures calculated for Seasonal Adequacy and Supply Mismatch show that the performance of the operation decreases from the watercourse to the main-canal level. At a watercourse level, farmers compensate their deficits (-28% for Supply Inadequacy) by applying more water during the rest of the season leading to a value of zero for Seasonal Adequacy. Differences between watercourses, however, are relatively high as shown by the value 0.27 of the Equity Indicator (0.25 is considered the limit between fair and poor performances [Molden and Gates, 1990]). At higher levels, Supply Inadequacy is lower due to an excess of water supplied to the system, expressed by high values of Seasonal Adequacy and Supply Mismatch. These last figures indicate a relatively poor performance at main-canal level.

Table 10.4. Performance indicators at three levels of the CRBC Irrigation System, rabi 1991/92.

Level	Seasonal Adequacy	Supply Inadequacy	Supply Mismatch	Equity
CRBC ⁶⁰ head	70%	-11%	73%	—
Distributary 3 head	12%	-21%	37%	—
Distributary 3 watercourse	0%	-28%	40%	0.27

Impact on Agricultural Production (Output Performance)

Although farmers are said to be still adjusting to changes in irrigation water supply, the cropping intensity for different watercourses monitored in Distributary 3 is surprisingly close to the design value of 90 percent, with a low spatial variability over the watercourses (the coefficient of variation for the cropping intensity is equal to 0.02). However, large differences in terms of cropping pattern are reported from one watercourse to the other. The actual area under wheat is higher than the design value (55% versus 45% in the cropping pattern used for the design for the irrigation system; see WAPDA 1991, page 45), but the main differences lie in the areas under gram (a crop requiring very low irrigation) and sugarcane (with high irrigation-water requirements): for all the sample watercourses (see Figure 10.7), the percentage of the CCA under gram is higher and the percentage of the CCA under sugarcane is lower than the design values.

The differences in the area cropped for these two particular crops highlight the current transitory state with farmers still taking decisions as if the water duties would be lower than the present ones, and closing their outlets to prevent the water supply exceeding their requirements. The specific position of gram within a wheat-rice-gram-fallow cropping pattern and the competition in terms of irrigation water between sugarcane and rice during certain periods of the kharif season could be due to other factors to be taken into consideration in explaining differences between the design cropping pattern and the actual one.

⁶⁰ At the head of the CRBC canal, the 10-day RWS have been approximated to the ratio of water released at the head to volume of irrigation water recorded as such by WAPDA. Thus values given in the Table are underestimates of the real values for the different indicators.

Figure 10.7. Ratio of actual area under crop to design area, for 8 watercourses of Distributary 3 of the CRBC during rabi 1991/92.

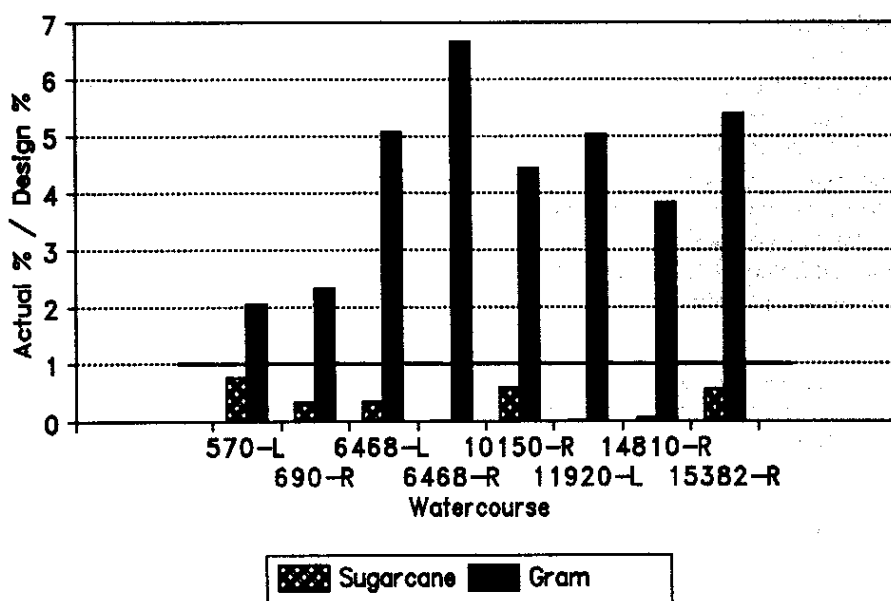
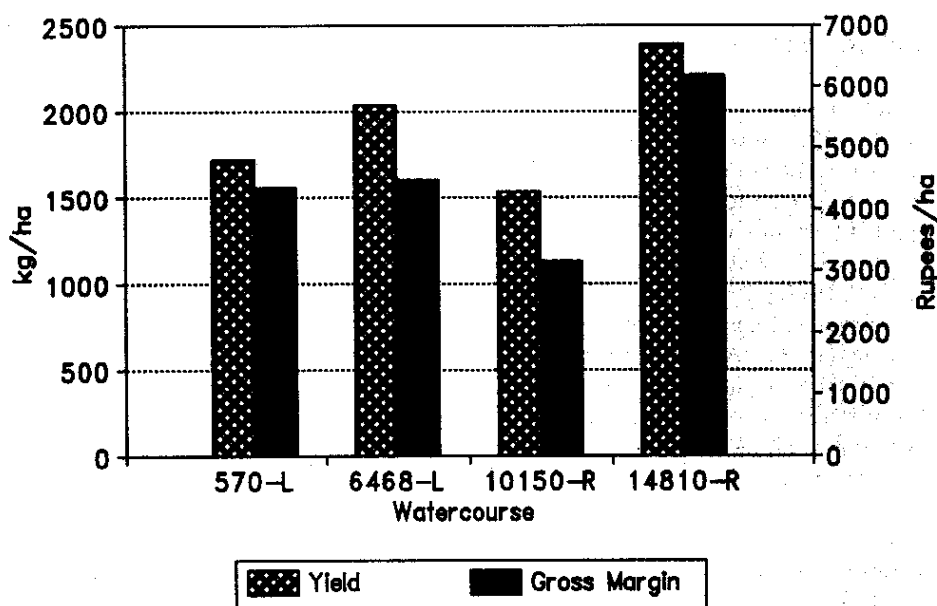


Figure 10.8. Yield (kg/ha) and gross margin (rupees/ha) of wheat crop for 4 sample watercourses.



The comparison between Seasonal Adequacy and cropping intensity shows a significant relationship between these two factors: the higher the cropping intensity, the lower the average RWS of the watercourse. To explain this relationship, however, is difficult and would certainly require a more in-depth analysis of the factors influencing the RWS at watercourse level.

Analysis of average wheat yields and gross income from wheat per watercourse shows that high yields and gross income per hectare of land are found when the average RWS is high. Figure 10.8 highlights the differences in both indicators from one watercourse to the other. It is interesting to note that the relative differences between watercourses is higher for gross margin than for yield, due to differences in costs of production. Wheat yields in the area are 20 percent higher than average values for the North-West Frontier Province.

The average productivity of water for wheat has been estimated for 4 sample watercourses. Table 10.5 shows its variability among these watercourses and gives the weighted average for them as well. Watercourse 14810-R has the highest productivity of water in terms of yield (kg) or gross income (rupees) per unit of water (m^3). The fact that some tubewells are still operated by tail-end farmers of this watercourse and that tubewell water has not been included in the "total quantity of water supplied" used to calculate the productivity of water could be an explanation of its much higher productivity. The differences between the other three watercourses are marginal. The comparison between these values and the average RWS for the four watercourses does not lead to any clear relationship between the factors involved, due mainly to the too low number of watercourses monitored.

Table 10.5. Average productivity of irrigation water for 4 sample watercourses: Wheat yield and gross margin per unit of water.

Watercourse	570-L	6468-L	10150-R	14810-R	Average
Yield per unit of water (kg/m^3)	0.25	0.26	0.25	0.42	0.30
Gross margin per unit of water (rupees/ m^3)	0.63	0.57	0.52	1.10	0.72

When converted into kg/mm , values of productivity computed for the four watercourses are really low (between 2.5 and 3.1 kg/mm) compared to values given by Bhatti et al. (1991) for Pakistan. The main reason for these differences, however, is that these authors use irrigation application data to estimate the productivity of irrigation water. In this case, because of the nonavailability of irrigation application data, values have been computed at watercourse level thus including conveyance and other losses (Garces et al. 1992) in the irrigation water supply. In fact, a large part of the water is lost before reaching the fields and thus could lead to serious problems of waterlogging, already existing in areas close to the head of the CRBC. But the gap between Bhatti et al. (1991) values and those presented in Table 10.5 still remains important even when subtracting conveyance losses from the supply at the head of a watercourse. A possible explanation of this difference could be the relative inexperience of farmers in the CRBC area and their inability to properly manage an adequate water supply at watercourse and field levels, compared to farmers in Punjab.

Limitations of the Indicators and the Data Collected

- WAPDA gatekeepers at the head of the distributaries report that often they partially close the gates during the night because few farmers irrigate and most of the outlets remain closed. This nightly decrease of the water supply has not yet been taken into account in estimating the water supply to distributaries or watercourses. The analysis of the data collected through automatic stage recorders installed at the head and tail of Distributary 3 would allow the modification of the supply factor of the RWS accordingly.
- The water requirements of the gram crop have been included in the calculation of the demand of water during rabi. However, gram is very rarely irrigated, being usually sown after rice to use the moisture remaining in the soil. Thus the requirements of this crop should be removed from the rabi season and included at the end of kharif season irrigation water demand.
- The same conveyance losses have been used to estimate the targets for the RWS. However, some field measurements have shown that losses could be different from one watercourse to the other, meaning that targets would be different as well. Thus the use of the Equity Indicator will have to be made cautiously.
- Although wheat is the most important crop during the rabi season, the economic indicators (weighted gross margin per unit of land and per unit of water) will have to be calculated by taking into account other crops grown by farmers of the Distributary 3 command area.
- It was not possible to collect data of irrigation applications at field level or farm level, due to the way farmers manage water below the outlet and the current status of organization of the irrigators. It is not possible to estimate the variability of the water supply, the RWS and the productivity of water within watercourses although the first year of data collection and field work have shown that this variability could be quite substantial.
- The canal-closure period has introduced a bias in two indicators, Seasonal Adequacy and Supply Inadequacy. These indicators will be more appropriate for the kharif season when the target used in the calculation of these two indicators and the target for the operators used in the calculation of Supply Mismatch are the same over time.
- The targets used for the calculation of the Supply Mismatch indicator would have to be modified in order to include the canal-closure period. A higher target for the periods preceding and following the canal closure will have to be calculated and fixed as targets for the operation of the main canal and the distributaries by WAPDA and the Irrigation Department.

DISCUSSION

Crop-Based versus Supply-Based Considerations

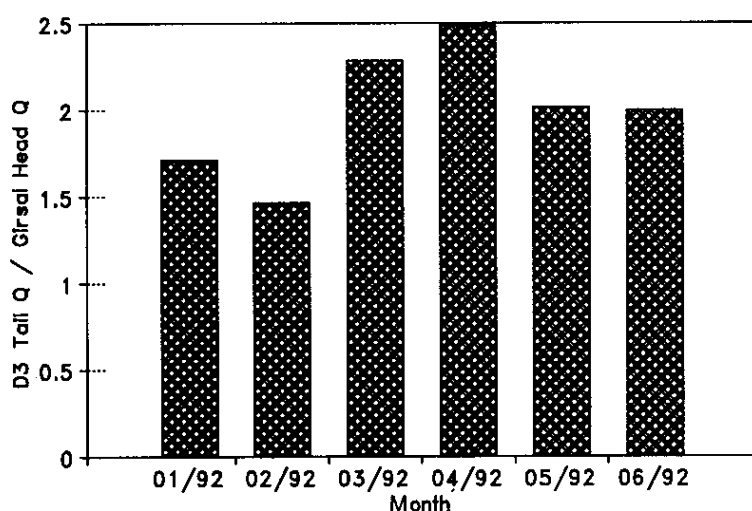
Although some periods of the season are characterized by an undersupply (equivalent to 28% of the appropriate supply), the quantity of water applied for the season equals the needs at watercourse

level. Farmers are managing their water below the outlet in a crop-based mode via a refusal system made possible by an excess of water at a distributary level and the capability to partially control the water going into the watercourse by closing or opening their outlets. Differences, however, exist among watercourses as shown by an equity indicator equal to 0.27. The differences within watercourses appear to be quite substantial as well and relate to nondevelopment of certain areas of the watercourse CCA: some farmers have an excess of water while others suffer a water shortage. Even if the RWS at watercourse level is close to the target, numerous losses within the watercourse lead eventually to relatively low yields, compared to the water available, and enforce the risk of waterlogging.

The distribution of water at distributary level is variable over time and seems to follow a pattern more or less related to crop water needs. However, two important aspects have to be considered: water is always supplied in excess at the head of Distributary 3 and changes in the supply appear to react to changes at lower level rather than follow a specific operation plan based on crop water requirements. Even the 40 days of canal closure do not compensate for the excess of water during the rest of the time (the RWS is on average 12% higher than the target at distributary level).

The larger-than-design cross section of Distributary 3 is the main reason for the operation of Distributary 3 at higher discharges than required. At the construction stage, Distributary 3 was provided with larger cross sections with the expectation that deposition of silt will take place and the cross sections will get reduced to the design sizes. After five years of operation, however, silt deposits have not developed.⁶¹ This problem has a direct impact not only on the RWS calculated at distributary level but also on the water released at the tail of Distributary 3. By design, the discharge of the water released at the tail should be equal to the discharge (supply) to the head of Girsal Minor. The monthly average ratio of these two discharges presented in Figure 10.9 shows

Figure 10.9. Ratio of discharge at tail of Distributary 3 to discharge (supply) at head of Girsal Minor, monthly averages.



⁶¹ The higher-than-design discharge could explain the absence of silt deposits at the level of the distributaries.

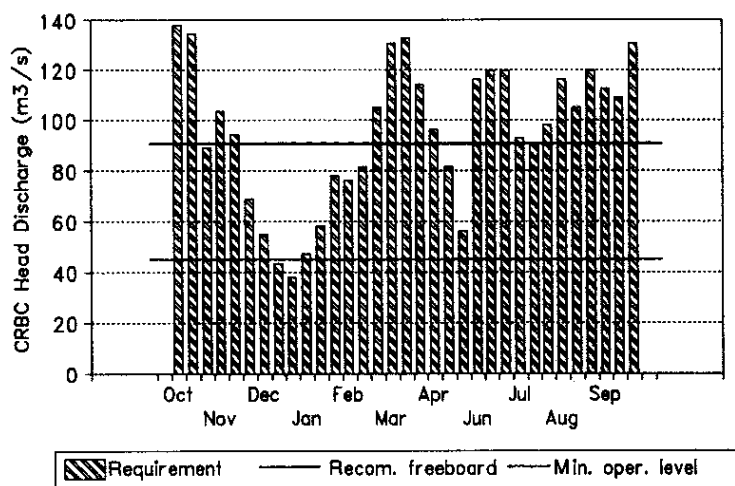
that the current situation is far from that designed (as stated in the section on Current System Operation and Operational Performance; page 258).

Whether the excess water is used downstream in the Paharpur Irrigation System should be ascertained and this would have an impact on the calculation of the productivity of water at the distributary level. If the water is used downstream, a better management of the water would improve the productivity of water for Distributary 3 but would not change the productivity of the total quantity of water available. It is interesting to note that the Supply Mismatch is better at distributary level than at watercourse level. Deviations from the targets for the different watercourses compensate for each other.

At main-canal level, when undersupply occurs, the deviation is only -11 percent from the target, due to the canal closure period; it is not due to an efficient (crop-based) operation of the irrigation water but to a general oversupply. On average, 70 percent more water than that required to irrigate crops has been released at the head of the CRBC and has escaped back into the Indus River ! The main reason for this, advocated by WAPDA, is that it is not possible to operate the CRBC at the very low discharges required for Stage I of the CRBC only; control structures are not adequate and the operation is constrained by the limitations of the canal system itself. To supply water adequately to all the distributaries of Stage I, WAPDA uses the Full Supply Level at the end of Stage I as the target for the operation of the main canal.

Investigations of the behavior of the CRBC using the simulation model SIC has supported the WAPDA position and shown that limitations will exist even when the three stages are operational. Problems of supplying the appropriate discharge to some offtakes exist at low discharge (less than 45 cumecs), while problems of inadequate freeboard appear for high discharges (more than 85 cumecs). The comparison between the irrigation water requirements (based on the design cropping pattern) and these two limits (see Figure 10.10) shows that for most of the year, required discharges are outside the range of 45–85 cumecs and thus cannot be accommodated by the CRBC under crop-based irrigation operations.

Figure 10.10. Physical system adequacy: Limitations at mail canal under crop-based irrigation operation (CBIO).



In fact, the objectives of crop-based irrigation operation (based on the design crop water requirements) could only be met 30 percent of the time with the current characteristics of the main canal. WAPDA, already aware of some of the problems, started to raise the banks at certain locations along the CRBC to increase the freeboard and maintain it below the accepted limit of 3 feet at high discharges.

Another aspect considered by WAPDA when operating the main canal is the problem of velocity and silt deposits. Although there is not enough silt in the unlined part of the canal, too much silt has been deposited in some places of the lined part close to the cross regulators. In some periods of the year, in order to wash the silt deposits, an excess of water is released at the head of the CRBC and it escapes at the level of the first cross-regulator. WAPDA tries to maintain a minimum discharge in the main canal to have a minimum velocity and avoid silt deposits in the lined section. This management of the system by WAPDA has a negative impact on the indicators based on the RWS.

Constraints on the operation, however, are not only related to the physical aspects of the system. WAPDA and the Irrigation Department (ID) do not have adequate staff to operate the system in a crop-based irrigation mode. The Irrigation Department, especially, finds itself in a very difficult position; while it had asked for a staff of 60 to operate Stage I of the new system, only 15 staff members (or 25% of its demand) have been allocated to the CRBC. Moreover, the communication systems of the Irrigation Department and WAPDA are inadequate; only a few regulating structures have been provided with telephone connections and there is no proper flow of information between sensible points being planned by the agencies (Garces et al. 1991).

Up to now, WAPDA and the ID have been quite static in defining new operation procedures for the CRBC Irrigation System. They do not have any operation plans for crop-based irrigation, although they react to changes in the water demand in the system over time. The conservatism of the two agencies is due to many reasons. An important one is that the Irrigation Department is an operating agency with a very low level of control over the system. All the control structures at main-canal level and at distributary-head level are within the hands of WAPDA. The Irrigation Department, for the first time, finds itself in the role of a subagency of WAPDA dealing only with the maintenance of the secondary canal system. This loss of power of control on the water flows combined with the control farmers have gained through the *pakka* structure at the head of the outlets weakens its position vis-a-vis the farmers as well.

Technical and Economic Considerations

Several indicators were defined and their calculations explained in the earlier sections of this paper. An important question to be addressed at this stage is how to establish a hierarchy of these indicators, technical or economic, according to importance or priority. For the different actors of the irrigated agriculture system, objectives are in fact different and the main indicators to be used will be different as well.

For farmers, economic indicators would be the first to be considered once they are sure of receiving a minimum irrigation water supply. It is assumed that farmers react as economic agents of the system and thus tend to optimize an objective function taking into account not only the maximization of their revenue, but also the minimization of the risk involved in their decisions or the maximization of a specific utility function.

For the operating agencies, these economic indicators are only secondary indicators. Technical indicators related to the operation of the system have much more importance as they are directly related to their daily work, tasks and responsibilities.

For policymakers, economic indicators are important as well, not only the returns per unit of land or the returns per farm but also the returns per unit of water. What is important here is related to investments in the use of a specific resource, water.

Finally, for IIMI researchers, it is slightly more difficult to make a choice. Economic indicators, on the one hand, are important to assess the impact of any change in the operation of the system to find out, whether it is beneficial or not, and as matters for discussion with policymakers and funding agencies. On the other hand, however, the operating agencies are the first clients of IIMI for the implementation of changes and thus have first to be convinced of the benefits (from their point of view as operating agencies) of management innovations. One could always expect that an improvement in the operation of the system (in terms of matching more closely irrigation water supply to crop water requirements) would lead to an improvement in terms of yields and agricultural production. This, however, has to be checked.

Implication of Results on Performance Assessment

The analysis of the performance of the CRBC Irrigation System under the current situation has shown that the performance of the system is low, mainly because the constraints in the system have led the different agencies to select a mode of operation based on aspects of supply rather than on crop water requirements.

The constraints imposed by the physical system have to be taken into consideration when evaluating the performance of the actual system and the changes in this performance due to innovations implemented jointly by WAPDA, the Irrigation Department and IIMI. Plausible targets for the operation will have to be selected and included in the calculation of the selected performance indicators in order to isolate the deviation in performance related to a poor management of the available water from the deviation related to constraints of the physical system.

The current objectives of the different operators involved in the CRBC Irrigation System (i.e., WAPDA [Barrage], WAPDA [CRBC], ID and farmers) have to be considered and analyzed. The formal and informal relationships between these groups and the way the information travels from one to the other will be of particular interest.

For the evaluation of the economic performance of the system, data will have to be collected to compute the selected indicators (GM_{ha} and GM_m^3) and these discussed with the agencies operating the system, with farmers and with the Department of Agriculture (AD).

CONCLUSIONS

The analysis of the present situation has shown that farmers are managing their water in a crop-based mode. There is no direct relation, however, between the operation at watercourse level and at higher levels of the system. At distributary and main-canal level, the main objective of the two agencies (WAPDA and Irrigation Department) is to operate the system in a certain range of discharges to cope with issues related to the operation of the canal itself rather than the demand for irrigation water. This disruption of the objectives is clearly seen in the values of the performance indicators chosen to characterize a crop-based system: the higher the level, the worse the indicators are (except for Supply Inadequacy), leading to a poor performance of the CRBC Irrigation System as a whole.

The selected performance indicators have to be tested and their behavior evaluated (robustness, sensitivity to extreme values, etc.). The analysis of the kharif 1992 data will be the first step of the evaluation to identify advantages and disadvantages of the indicators. An important aspect to be considered will be their effectiveness as communication tools with the operating agencies. For this specific purpose, RWS, for example, will have to be translated into discharges or efficiencies and intermediate indicators calculated and discussed with the operating agencies.

The different groups (WAPDA [Barrage], WAPDA [CRBC], Irrigation Department and farmers) have different objectives and do not have a proper system to communicate with each other. The Irrigation Department especially finds itself in a strange position between WAPDA and the farmers without controlling the flows of water into the distributaries or into the watercourses. The analysis of the objectives of the operating agencies and comparison with CBIO objectives will be a key component of IIMI's future research work in the CRBC area. The constraints in terms of resources available (funds and staff), differences between current objectives and CBIO objectives (see the third aspect of the Objective Setting Performance) will be evaluated and solutions to overcome them proposed. Results will have an impact on the performance indicators as well; better estimates of (attainable) operational targets at different levels of the irrigation system will be proposed and included in the calculation of the selected indicators.

Even if quite static, WAPDA and the Irrigation Department have started to address some of the issues related to crop-based irrigation operation (for example, WAPDA plans to increase the bank level at locations where there would be a freeboard problem for the highest discharges). Moreover, they have accepted the idea of collaboration with IIMI. In view of the project findings and their implications, three management "innovations" have been proposed by IIMI for implementation during the next rabi season and they have been accepted by high officials of WAPDA, ID and AD. The first "innovation" will address issues of the operation of the main canal and involve WAPDA; the second one will focus on the water supplied to distributaries and will involve the Irrigation Department and WAPDA indirectly; the third one is related to the lack of communication between the different groups involved in the operation of the system, especially between the end-users, the farmers, and the operating agencies. With the help of the Directorate of Agricultural Research and Extension of the AD, organized-behavior groups of farmers will be formed and will be involved in the operation of the irrigation system, a prerequisite for a successful crop-based irrigation operation, especially if water becomes scarce. For these management interventions, monitoring jointly by WAPDA, ID and IIMI will take place, leading to the analysis of the performance of the system with the proposed operations.

It seems important at this stage of the project to start discussion of the expected water scarcity with farmers and staff of the operating agencies. This situation is to be expected when Stage II and Stage III of the CRBC become operational with the command area of Stage I fully developed.⁶² This aspect will have to be taken into account when the modeling of canals is being done and when preparing operational plans with the agencies. For the operation of the water below the outlet, the actual flexibility seems to be sufficient and produces a good performance at this level. The situation with water scarcity, however, will be of prime importance at this level because important changes could be expected.

Further efforts have to be made to understand the irrigation system. The next steps in IIMI's research, with primary data to be collected by the IIMI field team, will have two important components. The first one will be the hydraulic modeling of the behavior of the distributaries (focus on Distributary 3) to identify problems of the operation at this level and to propose scenarios taking

62 It has been roughly estimated (based on PID *kharsra* data) that 25 to 30 percent of the total command area of the CRBC would not receive adequate water supplies if the current trends of water supply, cropping pattern and land development continue. This calculation, however, needs to be checked beyond the "back-of-the-envelope" approach.

into account constraints of the distributaries. The second one will be the economic modeling of farms to predict impact of changes in the irrigation water supply and irrigation system operation on the agricultural production.

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Appendix

MATHEMATICAL DEFINITION OF PERFORMANCE INDICATORS

Objective-Setting Performance

Allocation Adequacy

$$= \sum_i^n \left(\frac{|VOL_i - T|}{T} \right) / N$$

Physical System Adequacy

$$= \sum_i^n \frac{O_i}{N}$$

Operational Performance

Seasonal Adequacy

$$= \sum_i^m \left(\sum_i^n \left[\frac{RWS_{i,j} - T}{T} \right] / N \right) M$$

Supply Inadequacy

$$= \sum_j^m \left(\sum_i^n \left[\frac{Pa_{i,j} - T}{T} \right] / N \right) / M$$

Supply Mismatch

$$= \sum_j^m \left(\sum_i^n \left[\frac{|RWS_{i,j} - T|}{T} \right] / N \right) / M$$

Equity

$$= \sum_i^n \left(\frac{\sqrt{\left[\sum_j^m (RWS_{i,j} - (\sum_j^m RWS_{i,j}) / M)^2 \right] / M}}{\left(\sum_j^m RWS_{i,j} \right) / M} \right) / N$$

Output Performance

Weighted gross margin per ha

$$GM_{ha} = \frac{\sum^L (a_k * GM_k)}{\sum^L a^k}$$

Weighted gross margin per unit of water

$$GM_{m3} = \frac{\sum^L (a_k * GM_k)}{W_{m3}}$$

where T = Target (variable).

Vol_i = Volume allocated at the head of the CRBC for the period i .

$O_i = 1$, if the objectives of CBIO can be met during the period i ;
otherwise $O_i = 0$.

$RWS_{i,j}$ = actual RWS calculated for the period i at the location j .

$Pa_{i,j}$ = $RWS_{i,j}$ for $RWS_{i,j} \leq T$, equal to T otherwise.

a_k = area in ha under crop k .

GM_k = gross margin per ha for crop k .

W_{m3} = Total quantity of water (in m^3) supplied during the season to the area $\sum^L a_k$.

N = number of 10-day periods.

M = number of locations considered.

L = number of crops cultivated in the area.

CHAPTER 11

Production and Profitability of Rice Cultivation in Sri Lanka under Different Water Regimes — a Trend Analysis

C.M. Wijayaratna and K. Hemakeerthi

INTRODUCTION

RICE CULTIVATION CONTINUES to occupy a vital place in the Sri Lankan economy. Rice, the major staple food, accounts for over one third of per capita calory as well as protein consumption of an average Sri Lankan. Rice-grown areas stretch over a large extent in the country and in most of these areas it is the major economic activity. Rice-growing areas can be divided into three categories based on the source of water supply: cultivation under major irrigation schemes, under minor irrigation schemes and under rain-fed conditions. In 1990, rice was cultivated in 735,000 hectares (ha) and this was 41 percent of the total agricultural land use (Central Bank of Sri Lanka 1991). Over 80 percent of the total output comes from the irrigated rice areas. In the recent past, major irrigation schemes have become increasingly important in respect of area covered, productivity per unit of land and in the overall contribution to national production.

Attainment of Self-Sufficiency in Rice

The successive governments of Sri Lanka, as in many other countries of South and Southeast Asia, have followed a policy of achieving food self-sufficiency. Instruments employed to attain the objectives of self-sufficiency included a complex range of policies that appears to have had a significant impact on various aspects of rice production. Some of the measures that have been taken in the past are: the agricultural credit scheme which was introduced in 1948 and which has been operated as the New Agricultural Credit and Comprehensive Rural Credit Scheme since 1967; the Fertilizer Subsidy Scheme introduced in 1951; the Paddy Lands Act of 1958; the Crop Insurance Act that gave legal sanction to the Crop Insurance Scheme which was initiated in 1958; the Irrigation and Land Expansion Policy of successive governments through construction/maintenance of major and minor irrigation schemes; the guaranteed price scheme started in 1948; and the introduction of high-yielding varieties (HYVs) of crops associated with efficient research and extension services. As a result of these measures output enhanced and rice imports have gradually declined. During the last four decades, Sri Lanka has accomplished substantial achievements in rice output. These achievements are best illustrated by the changes in the rate of self-sufficiency in rice during this period. Just after independence in 1948, the country produced only 40 percent of the total rice requirement and the remaining 60 percent was imported. By 1985, self-sufficiency in rice reached a level of more than 90 percent. Rice imports, which increased to over 0.7 million metric tons of rough rice in the mid-1960s, decreased to about 20

percent of the peak level by the mid-1980s (Aluwihare and Kikuchi 1991). In 1985, domestic rice production was 2.660 million metric tons and rice imports were 0.22 million metric tons. However, in 1990, the total production was 2.538 million metric tons. Sri Lanka failed to surpass the levels achieved in both yield and production thereafter.

Productivity, Yield Gap and Contribution of Water

In 1983, the average productivity of rice in Sri Lanka reached a record level of about 3.6 mt/ha, but this is far below the level that could be reached as demonstrated by research scientists (approximately 10 mt/ha in 4–4½-month-age and 3–3½-month-age classes of HYVs). In this particular year, the yields obtained in an "irrigated district," namely Polonnaruwa, were 4.2 mt/ha and 4.5 mt/ha in *maha* (wet) and *yala* (dry) seasons, respectively.

The Future Demand for Rice

Despite the fact that Sri Lankan agriculture has managed to attain a higher degree of self-sufficiency in the major staple, population growth, urbanization and rising affluence (at least in certain strata of the population) will increase the demand for rice in the future. Even though the growth rate of the population of Sri Lanka is low by "Asian standards," the population may not be stabilized in the next few decades. Despite the increased emphasis on nonrice food crops, the demand for rice will continue to grow for sometime.

Future Supply

Future increase in rice production will depend mainly on: a) the scope for area expansion, b) yield increase and c) increasing cropping intensity (or time productivity). Profitability will also depend on these factors and the prices of inputs and output.

As explained elsewhere, in order to increase production, successive governments have relied primarily on rapid expansion of the area under cultivation. Nevertheless, the potential for future expansion is very much limited and the cost of capturing and developing new sources of water is escalating.

The cropping intensity in irrigated areas has been fluctuating in the range of 1.0 to 1.4 over the past two decades. It would be useful to analyze the factors influencing the cropping intensity and examine whether the farmers have achieved the maximum possible levels.

In the late 1970s, scientists believed that there is a significant amount of "untapped yield potential" in irrigated production systems, especially in Asia. Moreover, they observed that much of this could be captured by improvements in crop management in general and in water management in particular. Surprisingly, by the end of 1980, some researchers have observed a stagnating or declining trend in productivity of major food grains grown mainly under irrigation.

For rice, the major crop under irrigation in most Asian countries, recent studies indicate that the technological yield frontier⁶³ has stagnated and shows signs of long-term decline (Pingali, et al. 1990; Flinn and De Datta 1984). Evidence of farm-level decline indicates that farmer yields are catching up with the yield frontier and that further exploitation of the yield gap is not economical (Pingali et al. 1990). Incremental costs of achieving further yield gains exceed the incremental returns (Pingali 1990). Similar trends in declining rice yield have been observed in other experiment stations in India, Thailand and Indonesia (Pingali 1990).

It would be useful to examine the relevance of these findings to the Sri Lankan situation. If these are true for Sri Lanka, then the policymakers will have to turn to alternative solutions in supplying the major staple in sufficient quantities.

Moreover, as there are plans to allocate a significant portion of the country's rice fields to grow nonrice crops (other field crops) during the dry season, it is important to analyze: a) how this could be done while maintaining rice production at acceptable levels; and b) economics of rice production in sufficient depth.

The relationship between the rate of rice production growth and the in-demand growth is critical. If a higher production growth rate continues for a much longer period it could lead to a surplus production resulting in drastic price reductions or in forcing the government to introduce a subsidiary system. Such price reductions may force the farmer to use minimum inputs resulting in low production in the irrigation system. On the other hand, if growth in production fails to meet the growth in demand, strenuous efforts will have to be made to increase rice yields as almost the entire production growth will have to come from the yield growth and possible increases in cropping intensity since further opportunities for the expansion of area to be cultivated are minimal.

In addition, it is important to find out whether the rate of price escalation of inputs is consistent with that of the market price of rice in the recent past. The removal of the fertilizer subsidy, depreciation of the currency (Rupee), increases in fuel costs, etc., have affected input prices to a great extent over the years. In Sri Lanka, it is customary to provide hired laborers with free food under informal work contracts. Consequently, increases of food costs directly influence the crop budget. Also, cash input prices along with the cost of labor are likely to continue to rise in the years to come.

This condition will be further aggravated because the percentage of farmers engaged in rice cultivation on small landholdings is very high and they have limited "roots" in off-farm income sources. The opportunities for conventional alternatives such as "chena" cultivation are fast disappearing. At present, Sri Lanka lacks a strong sector of agro-based rural industries which can act as the interface between the peasant farmer and the industrial world. Such an interface might help convert the surplus agricultural labor, if any, to productive entrepreneurs or industrialists. Also, the capability of the industrial sector to absorb the marginalized farmers is still almost negligible. Under such a situation, it is of paramount importance to improve the productivity of existing rice areas, especially that of irrigated production systems. Hence, a study analyzing the trends of production, productivity and profitability of the land under the major staple in irrigation systems is crucial.

Unfortunately, in Sri Lanka, since the mid-1980s, there is a dearth of studies analyzing the performance of the main crop that is grown in irrigation systems. Accordingly, a proper understanding of the recent trends in production, cost of production, and profits with regard to rice cultivation under irrigation is indispensable. A comparison of the performance of the rice crop

63 In this paper, "frontier" indicates the distribution (or the trend) of the highest average crop yield obtained by farmers over time. Similarly, a "technological yield frontier" may represent the highest yields obtained at experimental fields. An average frontier function may be derived by taking the crop yields obtained by the top 5-10 percent of farmers in each season/year.

with irrigation and without irrigation is necessary to comprehend whether the use of irrigated water for rice cultivation has made an economically significant contribution.

Under these circumstances, it is of paramount importance to address such research issues as:

- a) How did the growth of rice production change over the years? Is Sri Lanka (as a whole or in different water regimes) undergoing stagnation or decline at the technological yield frontier? And what are the causes behind these changes?
- b) What are the trends in the cost of rice production, the composition of input costs, and their rates of change in recent years? Also, what are the reasons for the trend in the cost of rice production?
- c) How did rice profits vary in the recent past? Is the current local market price realistic? Could we anticipate any changes in the price of rice in the near future? And what is the thrust behind the outcome?

Study Objectives

The specific objectives of this study were:

- 1) To appraise trends in production, the cost of production and profits in rice cultivation in relation to water availability; this study attempts to examine the relevance of the International Rice Research Institute (IRRI) findings to the Sri Lankan situation — more specifically to check if there is stagnation or decline at the technological rice yield frontier in Sri Lankan irrigation systems.
- 2) To analyze the trends in input use in different water regimes. This analysis includes the composition of input costs and the rate of change as well.

By doing so, this study, which is similar to studies undertaken in other countries, has made an attempt to fill the vacuum prevailing in Sri Lanka. Provision of a sound base for future researchers and making a contribution to our practical knowledge were the other objectives of the study.

Methodology

Multiple sources of evidence were used in the study and included a review of recently conducted studies. The main secondary sources of data were the Department of Agriculture, Department of Census and Statistics and the Central Bank of Sri Lanka. This study focused on the period from 1980 to 1991 and follows a study by Attanayake and Wijayarathna (1986 [Mimeo]), which provided a detailed analysis on the same problem up to the mid-1980s. Also, international sources such as IRRI studies (Pingali, Moya and Velasco 1990 and Rosegrant and Pingali 1991) were used to learn about the work done on this subject in other Asian countries.

Sample. The study first analyzed the trends in production, costs and profits at national level. The next step was a brief examination of the differences in production between areas under major and minor irrigation schemes and rain-fed areas.

The next level of the analysis was an investigation of production performance of the rice crop in three districts belonging to different water regimes. These districts, namely Polonnaruwa, Kandy, and Kurunegala, represent the dry zone, the wet zone, and the intermediate zone, respectively. Availability of water was an important criterion for grouping the districts. This is because there are complex interactions between the use of the other inputs and the availability of water.

The selection of a district as a unit of analysis coincided with the criterion adopted by the Department of Agriculture in generating its cost of production data for different crops. Also, Attanayake and Wijayaratna (1986 [Unpublished]) had used the same criterion and had selected the same districts for their study. Hence, the selection of these districts ensured the continuity of the efforts.

Besides, variability within a climatic zone is too broad to be considered as a determinant of water availability. For instance, in spite of higher rainfall, most of the wet-zone areas face water shortages at times owing to: 1) the poor distribution pattern of rainfall; and 2) the lack of appropriate water control measures.

Polonnaruwa District, which belongs to the dry-zone low-country 1 (DL1) agro-ecological zone, has about 90 percent rice lands with reliable sources of water for cultivation. Kandy District, which falls within the wet zone, covers mainly the wet-zone mid-country (WM), and partly wet-zone upcountry (WU), and intermediate-zone low-country (IL) agro-ecological zones. It is important to indicate that there is little difference between irrigated and rain-fed areas in the Kandy District because of the well-distributed and sufficient rainfall in the rain-fed area. Kurunegala District is in the intermediate zone and consists mainly of intermediate low-country 1 (IL1) and intermediate low-country 3 (IL3) agro-ecological zones. Major irrigation schemes with reliable water sources are few while the outstanding feature of Kurunegala District is the predominance of numerous minor tanks that characterize risky cultivation. This places Kurunegala District below Polonnaruwa District, as far as water status is concerned, despite the higher rainfall recorded by the former.

Analysis. The following basic steps were involved:

1. Deriving the trends in productivity using regression techniques, ($y = a + bx$), where,

y = dependant variable (productivity) (kg/ha),

x = time variable,

a = intercept term,

b = average annual change in y .

2. Estimation of total cost of production per unit of land in terms of nominal and real prices by calculating the costs of items classified in terms of input type, total labor (family and hired), farm power, fertilizer, pesticides, seed rice, etc. The computation of real values will be done by two alternative approaches:
 - (i) By using the Colombo Consumer Price Index (CCPI) to deflate the cost of production of rice in other districts, it is easy to comprehend the outcome as the CCPI is a widely used indicator.
 - (ii) By employing the producer price of rice to treat the input costs and cost of production in order to express them in rice equivalents. The base year for this too will be 1985. Since interdistrict variation in costs of different items is negligible, it is hoped that comparison of costs will give an indication of input use under different production situations.

- 3) Comparisons of gross returns and net returns to unit of land, family labor, and capital investment in terms of nominal and real values.

Limitations

Due to nonavailability of a suitable indicator for selecting two water regimes at district level, the alternative of "rain-fed" versus "irrigated" conditions has been used. The rationale for using rain-fed/irrigated conditions of districts as a selection criterion is discussed here.

The Department of Agriculture has not published cost-of-cultivation data for 1988 and 1989 owing to the unsettled situation that prevailed in the country during that period. Therefore, the years 1988 and 1989 have not been included in the detailed analysis on cost of production. Also, the Department of Agriculture has changed its selection criteria of districts to represent rain-fed and irrigated areas. Since 1989, only a limited number of districts have been selected to represent each agro-ecological zone. Only those districts with a significant extent cultivated to rice have been selected to represent a given agro-ecological zone. A specific study area within a given district was then located to represent the most important water regime under which rice was being cultivated in the district. This selection criterion has removed some water regimes in the districts under consideration. For instance, the Department of Agriculture does not publish data on rain-fed areas in Polonnaruwa District. However, in this analysis we treat Polonnaruwa as an irrigated district.

Organization of the Paper

This paper is organized in four sections. Following the introductory section, the second section (Production Trends) describes the changes in production and productivity and examines policy as well as other factors contributing to such changes. In the third section (Trends in Cost of Production and Producers' Profit Margins), an attempt is made to analyze the cost of production and its structure with special emphasis on identifying the components of the cost structure, especially those accounting for high proportions of the total cost. The same section also examines the profitability of rice farming through returns to some selected factors of production. Analysis of farm costs and returns are converted to *real terms* using rice prices as the adjusting factor. This methodology is described in detail in the third section. Apart from this, in the third section, an attempt is made to contrast cost-effectiveness of rice farming under different production situations or water regimes. The last section (Policy Implications) presents a summary of findings and policy implications of trends observed in the rice sector over the recent past.

PRODUCTION TRENDS

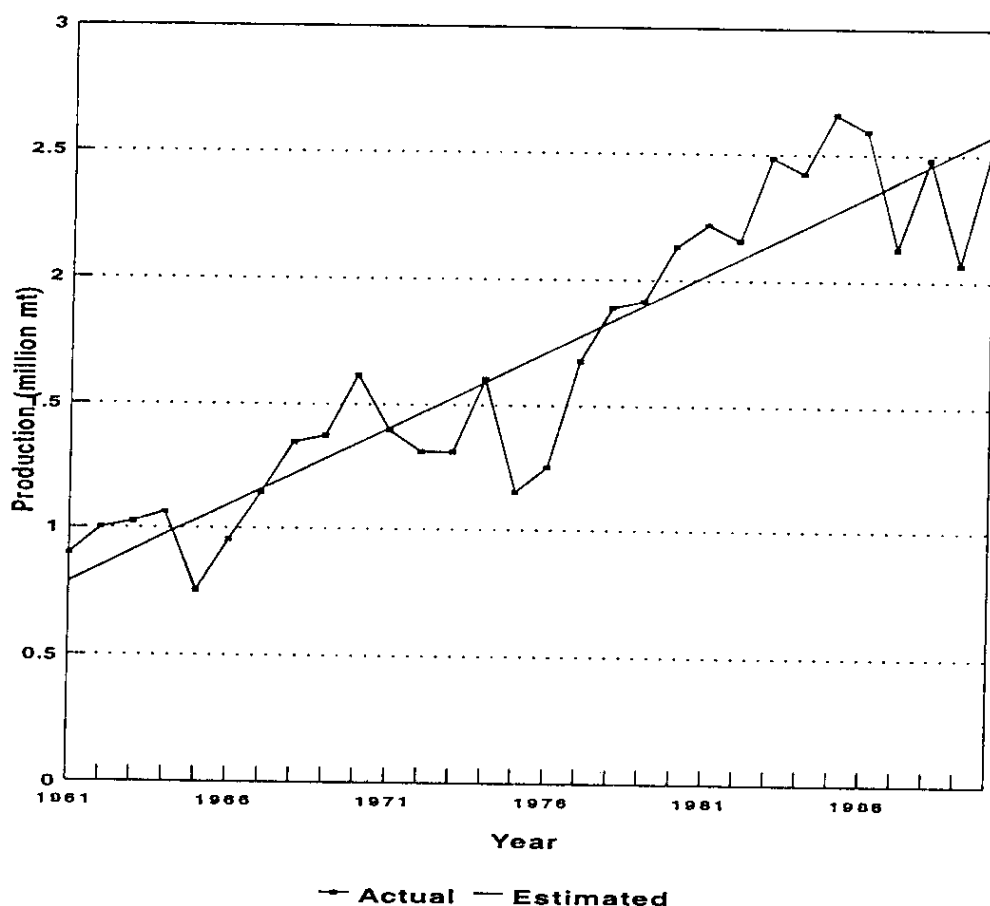
The objective of this section is to review the trends in rice production with a comparison of districts that represent different water regimes. Besides the data related to selected irrigated areas, national-level data and the data related to rain-fed areas will be analyzed in order to see the magnitude of the difference in the levels of production between irrigated and rain-fed areas. The discussion deals with the changes that have occurred in production and productivity since the 1980s and briefly investigates policy as well as other factors that have contributed to such changes. In addition to the analysis of current trends, it attempts to look for their associated causes. These, in

turn, will also be helpful in understanding the level of success of the services rendered by the state to the farmers in irrigated agricultural production systems. More emphasis is given to the period since the mid-eighties. Whenever necessary, reference has been made to important previous periods such as the early sixties, when the green revolution emerged.

National-Level Production Trends

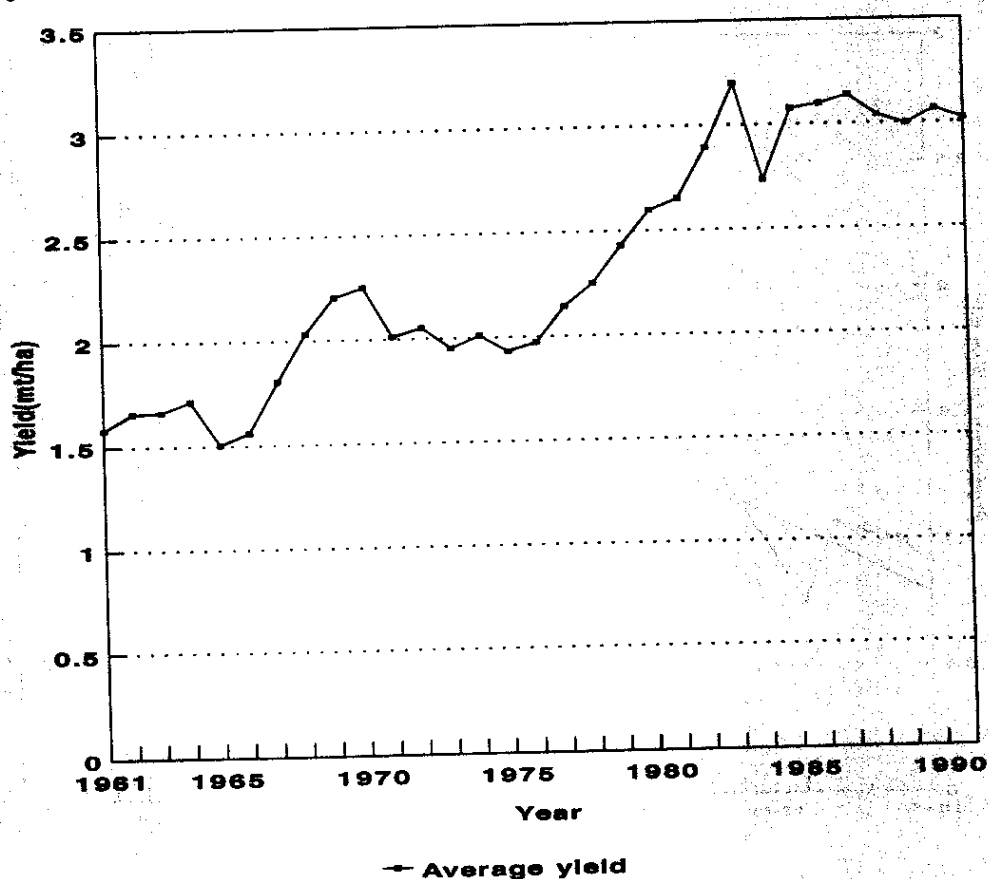
In the three decades beginning with 1960, during which the spread of new high-yielding varieties was prominent, the total output of rice increased substantially from 897,000 metric tons in 1960 to 2.389 million metric tons in 1991 (Aluwihare and Kikuchi 1991 and Department of Census and Statistics 1991). Figure 11.1 shows the trend of rice production between 1961 and 1990. Rice production showed a significant increasing trend and a maximum annual increase was displayed just before 1985.

Figure 11.1. Trend of rice production, 1961–90, Sri Lanka.



The highest annual rice production, 2.66 million metric tons, was reported in 1985. There was a 3.8 percent annual increase between 1980 and 1985. Apparently, 1985 is a turning point in the recent history of rice production in Sri Lanka. The post-1985 period does not show a significant change of annual rice production. The area cultivated to rice and the national average of rice yield also "remained" at their peak levels reached by the mid-1980s. The highest rice yield per hectare (3.606 mt per ha) was reported in 1983 (Figure 11.2). However, the following year was dissatisfying and the yield dropped to 3.076 mt per ha. The excessive rains and floods which prevailed during the early parts of 1984 were mainly responsible for this yield drop. The total national rice production, which reached the highest level in 1985, suffered a slight setback in 1986. The drop of production was mainly evident in the reduced 1985/86 maha harvest. As the Central Bank of Sri Lanka Annual Report (1986) indicates, a very significant decrease in output was reflected in the rice producing districts of the Northern and Eastern provinces. The high incidence of crop failure and the breach of the Kantale Dam may also have affected the rice cultivation, particularly in the Trincomalee District. These, in turn, would have contributed to the low output in these areas.

Figure 11.2. Trend of rice yield, 1961-91, Sri Lanka.



Rice production in 1987 dropped by 18 percent over the previous year. The prolonged drought that prevailed in most of the major rice producing areas was mainly responsible for the production decline in 1987. The shortage of water not only delayed the commencement of cultivation and reduced the extent sown but also led to a reduction in fertilizer application (see under Cropping Intensity, p 291) and in the extent harvested which, in turn, resulted in a lower production. However, it is important to indicate that even though the total production declined, the productivity or the average yield per hectare in 1987 increased by two percent over the 1986 yield owing to the performance of major irrigation systems. The highest average yield per hectare in the maha season, 5.97 mt/ha, came from the Uda Walawe area, which was a 17-percent increase over the previous season. Also, System H in the Mahaweli Project recorded the second highest yield of 5.27 mt/ha. The total gross extent harvested in 1987 recorded a 19 percent decline over the previous year. Furthermore, the difference between the extent sown and the gross extent harvested in 1987 was fairly large; harvested extent in 1987 amounted to 102,479 ha or 13 percent of the gross extent sown.

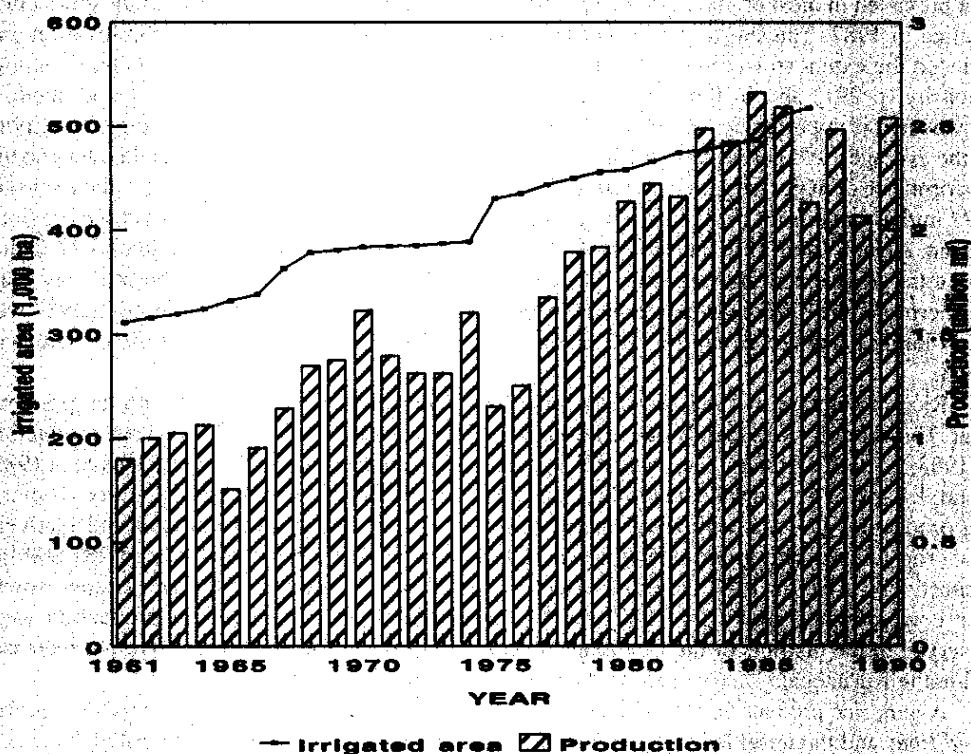
Rice production in 1988 showed a remarkable recovery when compared with the previous year. This recovery was mainly due to the ending of the drought. However, the total rice production in 1988, 2.5 million metric tons, was still 6 percent less than the production level achieved in 1985. Central Bank of Sri Lanka data (1988) shows that despite a decline in average yield per hectare, this production gain was achieved primarily as a result of increased gross extent sown and relatively low crop failure. The gross extents sown in 1988 and 1989 were 865,000 ha and 781,000 ha, respectively. Also, in 1988 the gross extent harvested was 94 percent of the gross extent sown. The corresponding figure for 1987 was 87 percent. Substantial increases in production were observed in the districts of the Dry Zone. Vavuniya District recorded a nearly fivefold increase, while the Kurunegala District recorded a more than threefold increase.

Again, rice production suffered a severe setback in 1989 due mainly to *unfavorable weather conditions* and the unsettled situation that prevailed in the country. The area harvested decreased to 690,000 ha and the average yield dropped to 3.37 mt per ha. **The determination of the extent of the contribution of soil degradation to the apparent drop or fluctuation in production was not attempted due to the inadequacy of data. However, it is clear that other factors such as weather conditions and other hazards have contributed to the fluctuations of production in the recent past.**

Rice production in 1990 was 2.54 million metric tons, showing a substantial increase of 23 percent over the production in 1986. Both maha and yala seasons contributed to the higher rice production, showing 23 and 24 percent increases over the respective seasons of the previous year. This production increase was mainly due to the improved security situation in the country and favorable weather conditions. In any case, the 1990 rice production was 5 percent lower than the highest production recorded in 1985.

According to the Department of Census and Statistics (1991), rice production in 1991 was 2.39 million metric tons, which was a 5.9-percent drop over the previous year. The rice production of 1.56 million metric tons recorded in the 1990/91 maha season was a 5.68-percent decrease compared to the previous maha season. This drop in the production could be attributed to the decrease in the sown area. The total sown area during the maha 1990/91 season was 500,509 ha. This is a 5.69-percent decrease over the previous season; decreases in sown area have been reported from Amparai, Ratnapura and Matara districts. Contrary to the decline in sown area, the rice yield per hectare showed a 1.6-percent increase in maha 1990/91. The Mahaweli System H area and the Uda Walawe area have recorded the highest average yields. There is little difference between the gross harvested extent of yala 1991 and that of yala 1990, but the average yield per hectare in 1991 dropped by 6.6 percent over the yala 1990 yield. Accordingly, there has been a 6.3 percent drop in the rice production in 1991 yala over the previous yala season.

Figure 11.3. Trends of rice production and irrigated area, 1961–90, Sri Lanka.



Trends under Different Water Regimes

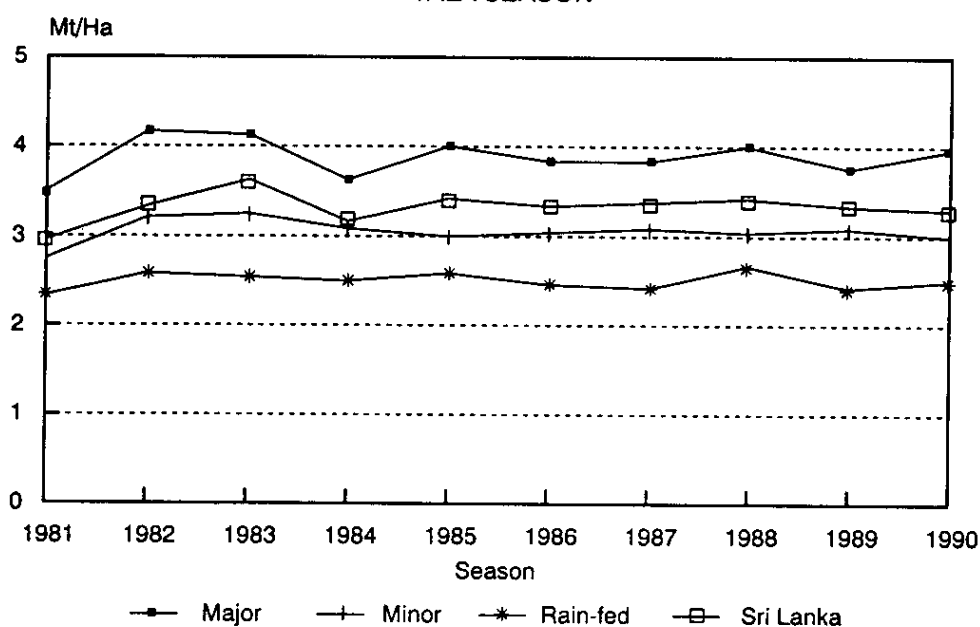
Figure 11.4 shows changes in the rice yield per hectare between 1980 and 1990 for areas under major and minor irrigation schemes, rain-fed areas, and the total cultivated area (national yield level). Major irrigation systems have been recording the highest yield levels, around 4.00 mt/ha, throughout the period. The national yield levels are somewhere between the yield levels for the major irrigation systems and the minor systems. Obviously, the rain-fed areas have recorded the lowest yield levels. Under rain-fed conditions, yala season yields have been significantly lower than the maha season yields. Generally, national yield levels remained at the same level throughout the decade from 1981 to 1990.

The Area under Rice Cultivation — Recent Trends

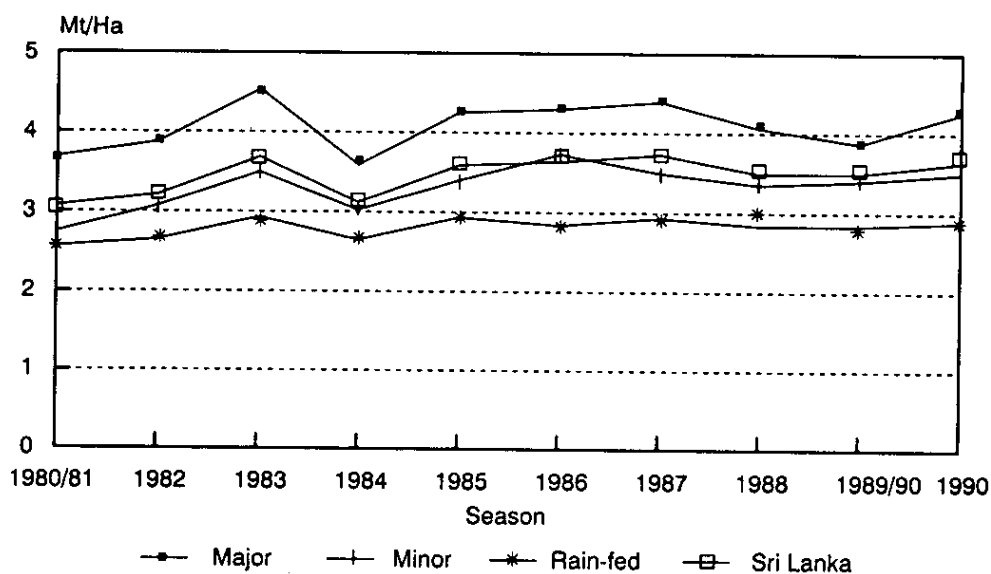
The area harvested, which was only 564,000 ha in 1960 increased to 886,000 ha, in 1984, which is the highest recorded so far. In 1991, the extent harvested was, only 741,000 ha. The annual variation observed was mainly due to different weather conditions that prevailed in the respective years. The increasing trend observed until the mid-1980s changed mainly because the total irrigated area did not increase significantly. This can be explained by looking at both the extent sown and the extent aswaddumized.

Figure 11.4. Changes in rice yield between 1980 and 1990.

YALA SEASON



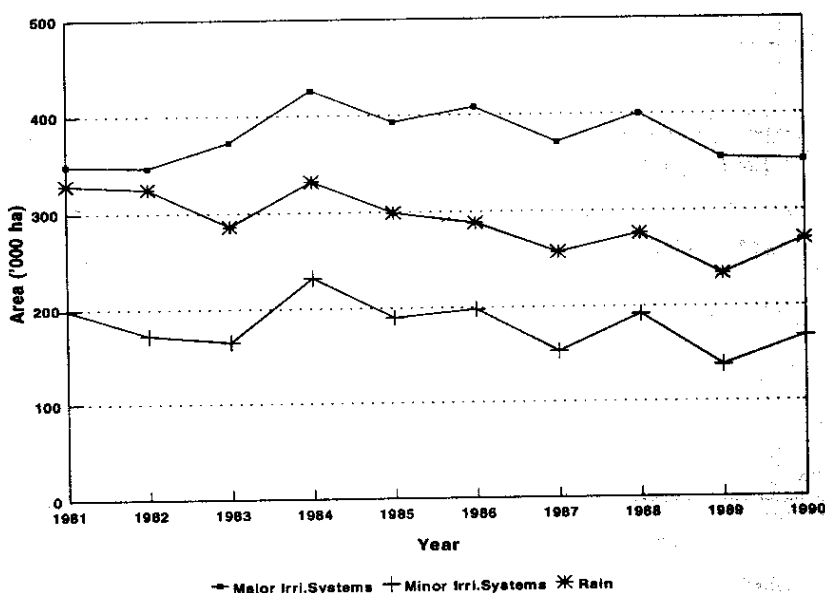
MAHA SEASON



Source (of primary data): Department of Agriculture.

According to Aluwihare and Kikuchi (1991) the total irrigated rice land area had increased from 253,000 ha in 1950 to nearly half a million ha in 1985, and 90 percent of this increase was due to the increase in the irrigated land area that had come under the major irrigation systems. The area under major irrigation systems was less than that of minor systems until 1966. The contrast of land expansion between major and minor irrigation systems is outstanding over the years: the areas that came under the major and minor irrigation systems were 81,400 ha and 159,000 ha, respectively, in 1948 and they increased to 310,522 ha and 179,311 ha, respectively, by 1990 (Department of Census and Statistics 1991). Major irrigation systems received a prominent place in the state development programs. However, by the late 1980s the construction phase had come near to an end (Figure 11.5).

Figure 11.5. Area cultivated to rice by type of irrigation.



Source (of primary data): Department of Census and Statistics.

Trends of Yield and Their Determinants

The average yield level achieved by the mid-1980s seems to be low when compared with the yield potentials of new, improved varieties. However, the average yield recorded in the mid-1980s represents an expansion of productivity by about 92 percent in relation to the level of 1960. The expansion of irrigation facilities and associated technologies such as the wide diffusion of high-yielding varieties associated with improved water conditions and increased levels of fertilizer application are basically responsible for this achievement.

The total increase in rice production between 1952 and 1985, and contributions of variety, fertilizer, and irrigation, according to Aluwihare and Kikuchi (1990), are summarized below:

	(1,000 mt)	(%)
Total increase	2,087	100
Increase due to:		
variety	861	41
fertilizer	561	27
irrigation	665	32

Rice Yield and the Contribution of Irrigation Facilities

With the expansion of irrigation facilities to a greater extent of rice lands that fall within the dry zone, the average yield of the crop has increased remarkably. This occurred, to reiterate, through increased and timely availability of water which is considered a major limiting factor of rice production, along with the seed-fertilizer technology. Response of rice plants to water differs from that of tropical upland crops, and this difference has important implications for irrigation as well as for varietal improvement.

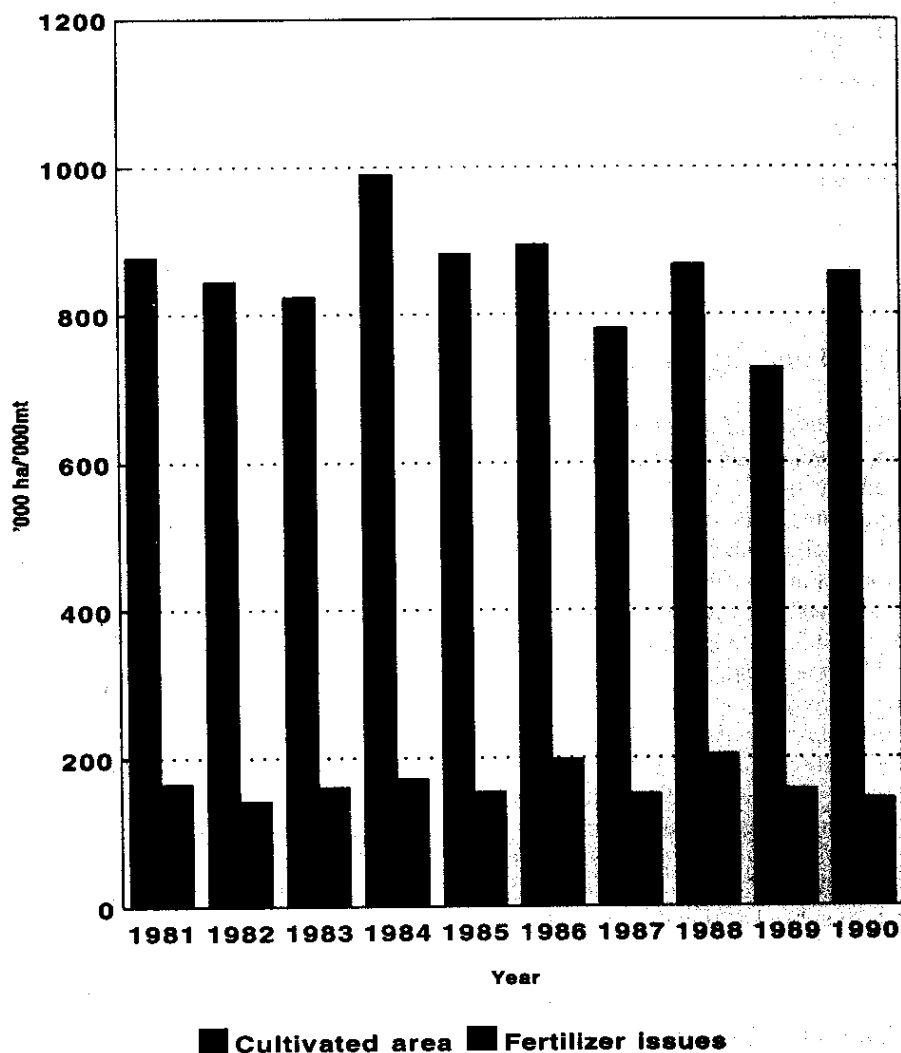
The highest average yield, 3.6 mt per ha, was reported in 1983. After 1983, the average yield varied around 3.0 mt per ha, without demonstrating any significant change. In 1991, the average rice yield in the island was 3.02 mt per ha (Department of Census and Statistics 1991). This is a 17-percent less than the 1983 average yield per hectare.

It is important to indicate that a high level of adoption of new, high-yielding varieties can be achieved easily because this is an innovation which does not involve much expenditure; any farmer can get some rice seeds from a neighbor without making a cash payment. However, that does not mean that a higher level of adoption of new varieties of rice ensures a higher yield level because these new varieties require excessive inputs, such as fertilizer and improved management techniques. Besides higher yield potential, diffusion of short-aged varieties offer higher crop intensification by changing the cropping pattern from single to double cropping.

Rice Yield and Fertilizer Use

There has been a tremendous increase in the use of fertilizer since the early 1960s. The amount of fertilizer used has increased from a mere 9 kg per ha in 1960 to 168 kg per ha in 1990 (Central Bank of Sri Lanka 1991). However, as Figure 11.6 shows, there has not been a significant increase in fertilizer use in the 1980s. The increase of fertilizer prices which came into effect with the removal of the subsidy at the beginning of 1990 seems to have adversely affected the fertilizer issues in 1990 and thereafter. The fertilizer issues in 1990 amounted only to 143,565 mt, representing a drop of 8 percent over the previous year. The drop in the fertilizer use is significant, because in 1990, the area cultivated to rice crop has increased by 18 percent over the previous year. In other words, the average quantity of fertilizer issued per ha cultivated to rice has decreased by 22 percent, from 0.22 mt/ha in 1989 to 0.17 mt/ha in 1990.

Figure 11.6. Annual fertilizer use and area cultivated, 1981-90.



Source of primary data: Central Bank of Sri Lanka, 1990.

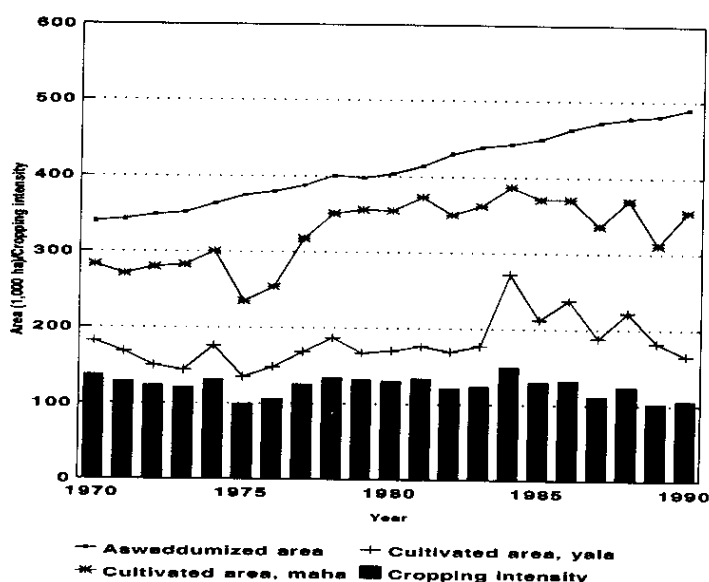
A distinct feature of Sri Lanka with respect to fertilizer use in the rice sector is that the price ratio between fertilizer and rice has been low because of heavy subsidies given to farmers to buy fertilizer. The nitrogen-rice price ratio has been far below 2.0 except in 1960. Consequently, the optimum levels are very close to the respectable maximum nitrogen levels that correspond to the maximum attainable yields. The actual levels of nitrogen per hectare were lower than the optimum levels. The gap between these two levels, however, have become narrower over time, and by 1985 the actual nitrogen use per hectare for each category reached a level that was 70.5 percent of the respective optimum level.

Aluwihare and Kikuchi (1990) conclude that the yield impact of fertilizer subsidy withdrawal would be small in the long run, in the order of 1 to 2 percent. Such a small impact is due primarily to the fact that the price elasticity of nitrogen demand is quite low because of the high nitrogen intensity before the withdrawal of the subsidy.

Cropping Intensity

Contrary to expectation, the cropping intensity has not shown a significant increase even by the late 1990s. The cropping intensity which was 136 in 1960 reached 145 in 1985, the highest recorded so far (Figure 11.7).

Figure 11.7. Cropping intensity, 1970–90.



Note: Major and minor categories included.

Source (of primary data): Department of Census and Statistics.

Expanding the “effective irrigated area” by increasing cropping intensity would be a more economical option, especially in areas where further expansion in the irrigated land frontier is constrained due to financial constraints, limits in water sources or supply, etc. Cropping intensity (or cropping index) is usually defined in terms of number of harvests per year from the same area of land. In order to eliminate the problem of differential characterization of long-season and short-season crops, and to reflect the degree of utilization of sunlight, Levine et al. (1988) suggest the use of *hectare-days*. This combines the area factor and the proportion of the year during which a particular crop could be in a stage of active crop growth. This may be improved further by incorporating a profit factor — profit per unit of water per year or profit per unit of land per day, etc.

Examples cited in the earlier sections of this paper included instances where management strategies or interventions resulted in substantial increases in the cropping intensity. This can be done effectively in several ways. Among them are:

- Introduction of short-age crops thereby increasing effective area under cultivation per unit of time.
- Multiple and relay cropping.
- Cultivation of 2-3 crops per year by adopting water saving techniques.

Staggering of land preparation, planting and other cultivation methods are common phenomena in many irrigation systems. Even though staggering may not be completely avoided due to some constraints (e.g., limitations in labor and farm power, water supply, etc.) "planned staggering" of cultivation may be helpful both in saving scarce water resources and in increasing the number of crops cultivated annually.

Disparities in Production among Districts

Data used for the analysis are those published by the Department of Agriculture and the Department of Census and Statistics. However, data for 1988 and 1989 are not available because the Department of Agriculture could not collect reliable data as a result of the unsettled situation in the country. The Department of Census and Statistics has covered 1988 and 1989 but its record does not give many details.

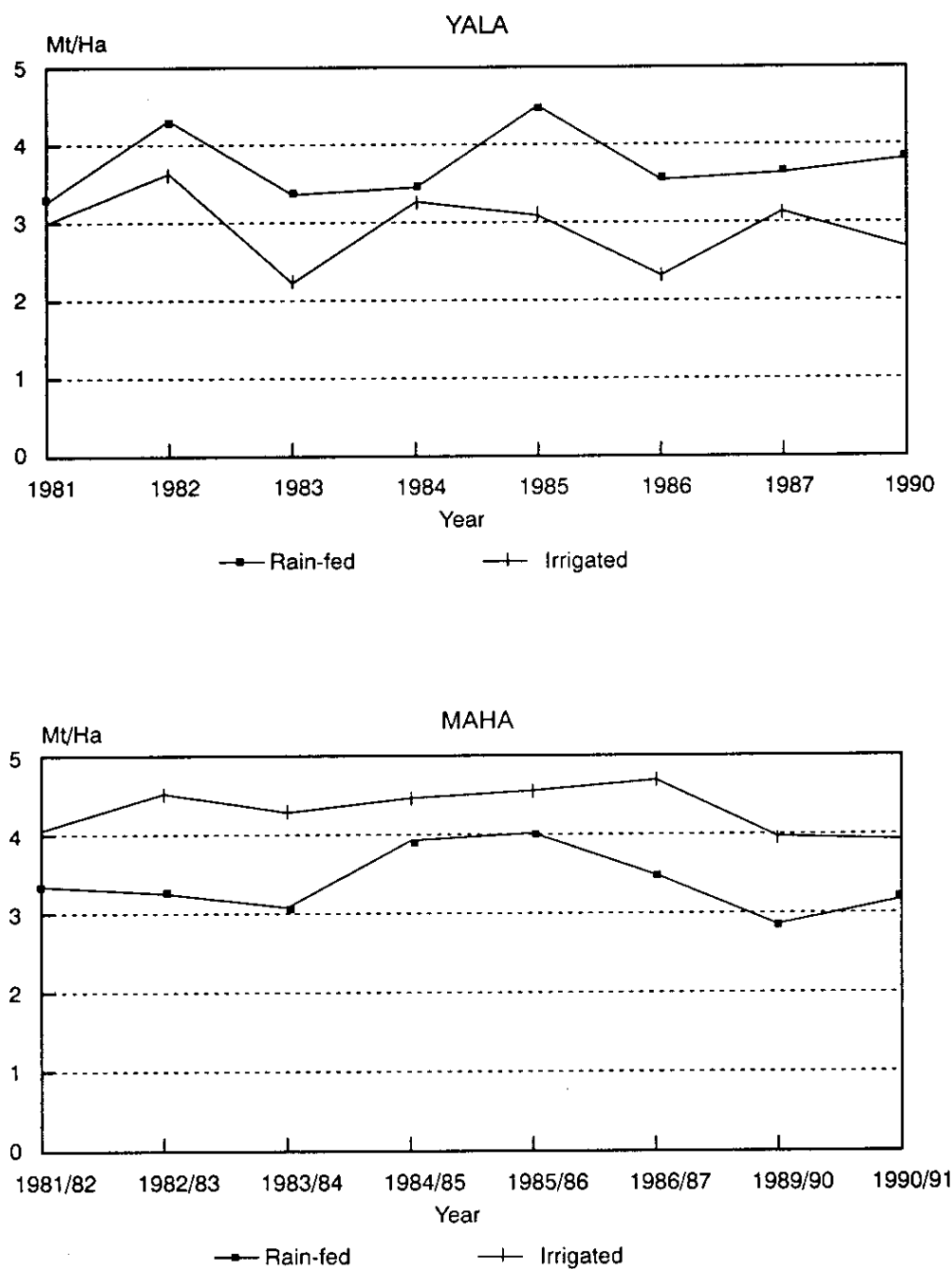
Apparently, the 1980s do not show a clear yield increase in the different water regimes under consideration. The yield levels recorded under irrigation are higher when compared with those under the rain-fed conditions, but they are far below the yield potential of modern rice varieties. This yield gap implies the importance, in regard to rice yields, of factors outside those of water.

However, this analysis at aggregate level does not represent the real picture at irrigation-system level. Within irrigation systems, a significant portion of gap may be existing and the gap could be explained by water inadequacies arising out of management problems.

Kurunegala District recorded the highest yala and maha yields in 1982 and 1985/86, respectively under rain-fed conditions. Under irrigation, the highest yala and maha yields were recorded in 1985 and 1985/86, respectively (Figure 11.8). Farmers who grew rice in rain-fed areas in Kandy District reported higher yields in yala seasons in the late 1980s when compared with the early 1980s (Figure 11.9). On the other hand, after the mid-1980s, farmers who grew rice in maha seasons received yields that were lower than the yields of the early eighties. Irrigated rice farms in Kandy and Polonnaruwa districts did not show any significant changes in the average yields in the 1980s (Figures 11.9 and 11.10).

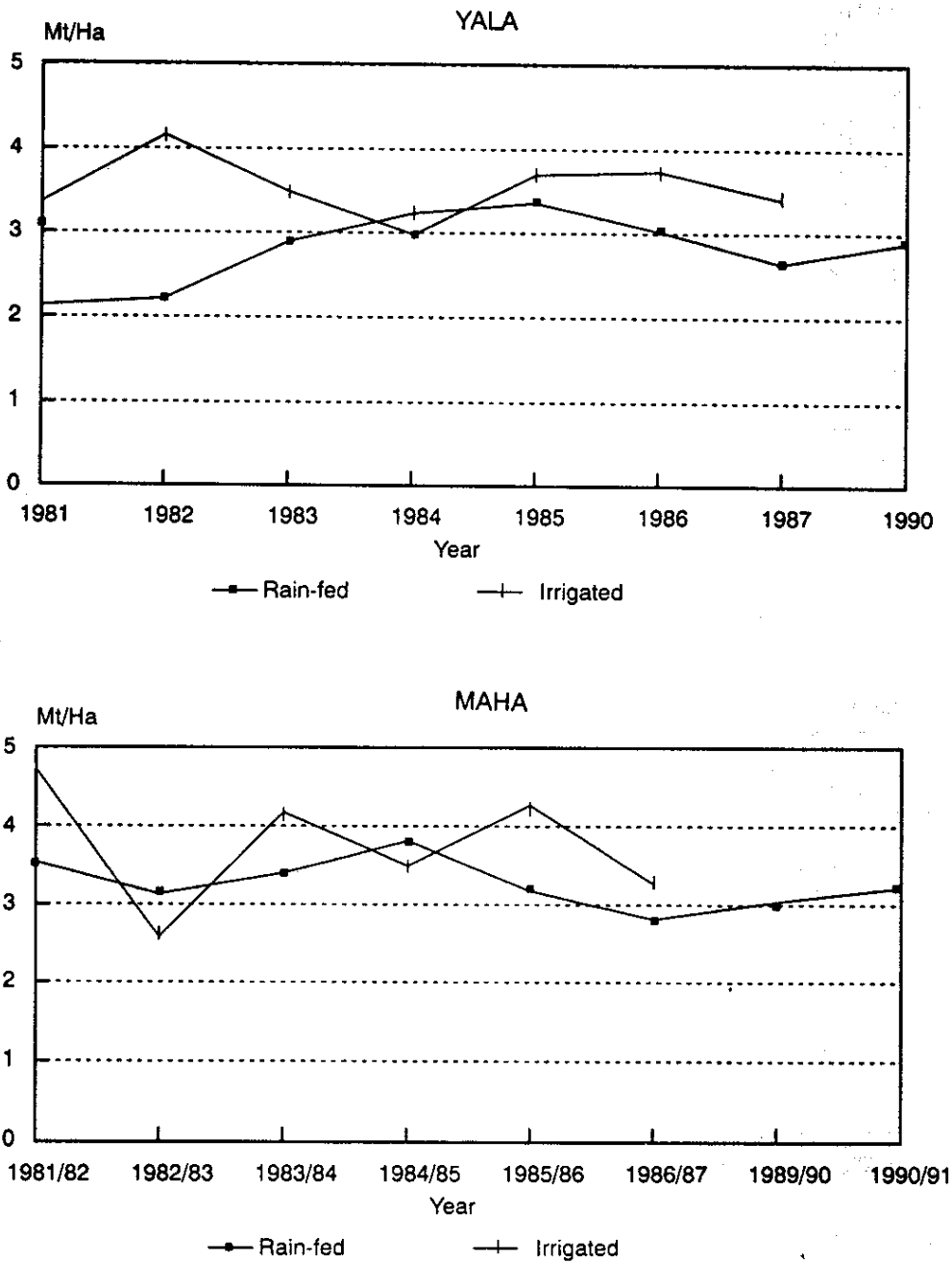
In yala 1986, all three districts under consideration experienced severe crop failures. Kurunegala District experienced the highest crop failure in the island in 1986 and the extent harvested was only 54 percent of the gross extent grown. The drought that prevailed during 1986 yala continued during 1986/87 maha as well. Except for Polonnaruwa, which maintained the production level achieved in 1985/86 maha, the other two districts experienced significant drops in production during the 1986/87 maha season. Kurunegala was among the districts which recorded substantial declines in the extent sown during 1986/87 maha (a decline to 56,580 ha from the 71,604 ha cultivated during the previous maha season). The highest crop failure during both

Figure 11.8. Changes in yield, Kurunegala District, 1981–90.



Source (of primary data): Department of Agriculture.

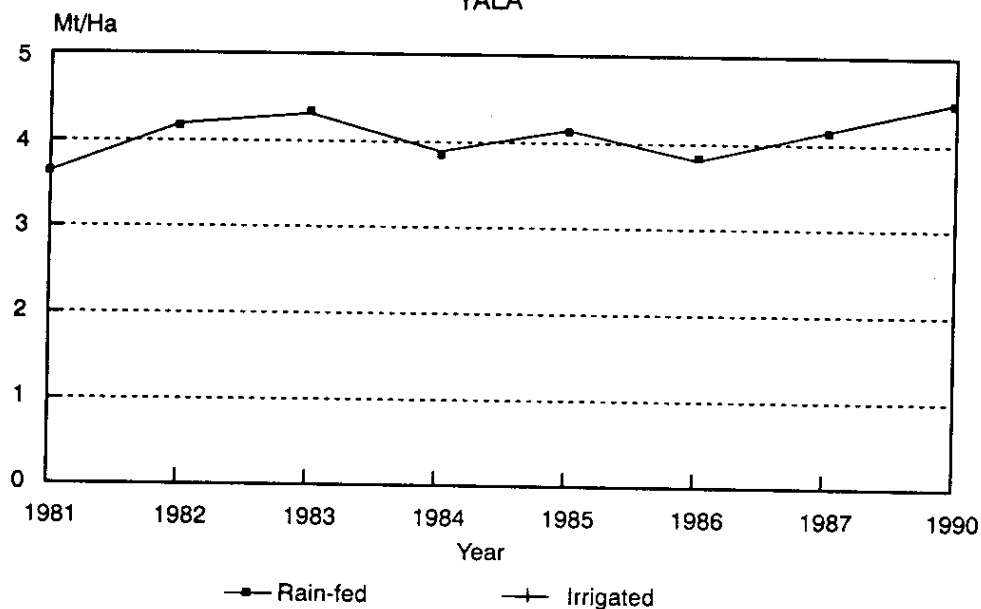
Figure 11.9. Changes in yield, Kandy District, 1981-90.



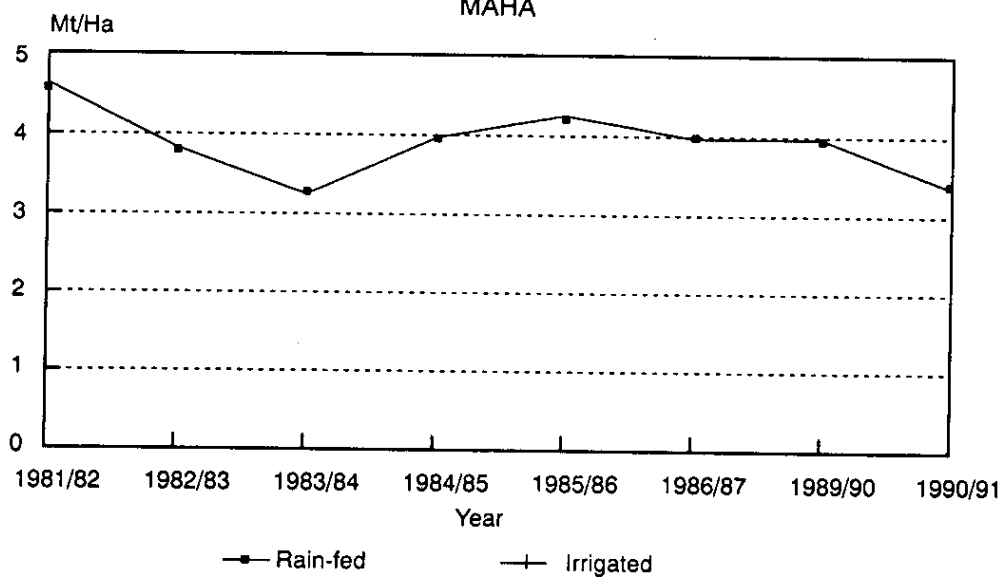
Source (of primary data): Department of Agriculture.

Figure 11.10. Changes in yield, Polonnaruwa District, 1981-91.

YALA



MAHA



Source (of primary data): Department of Agriculture.

seasons was in the Kurunegala District, which experienced the most severe drought conditions. The area harvested in the Kurunegala District was only 32 percent and 53 percent of the area sown in 1986/87 maha, and 1987 yala, respectively. The extent totally damaged by the drought in the Kurunegala District was about 50 percent of the gross extent sown in maha and 33 percent in yala.

In 1990, both Kurunegala and Polonnaruwa districts recorded substantial increases in the production of rice. These increases were achieved in spite of marginal drops in the yields per hectare, mainly as a result of substantially increased area sown and the increased area harvested due to favorable weather conditions (Figures 11.8 and 11.10). Kurunegala and Polonnaruwa districts along with those of Anuradhapura and Amparai, and the Mahaweli H area accounted for about 67 percent of the total increase in production during yala 1990.

The Gross Extent Cultivated. Kandy and Kurunegala districts do not show any increase in the extent cultivated to rice during the 1980s. The areas sown in 1981 and 1990 in Kandy District were 36,433 ha and 35,257 ha, respectively. The areas sown in Kurunegala District were 109,637 ha and 108,000 ha in 1981 and 1990, respectively. Polonnaruwa District shows a difference of about 38 percent in the area cultivated in the 1980s. The areas sown in 1981 and 1990 in Polonnaruwa District were 56,666 ha and 78,350 ha, respectively. It is evident from these figures that Polonnaruwa District has benefited from new irrigation development projects. The increase of the area from 51,457 ha to 76,178 between 1981 and 1990 is significant under the major irrigation systems..

Total Production. A comparison of data reported between the early eighties and the late eighties shows that among the three districts under consideration only Polonnaruwa has recorded a significant increase in the total production. If the decade 1981-91 is divided into two subperiods, 1981-85 and 1986-91, the average total production in Polonnaruwa District in the subperiod 1986-91 shows a 27 percent increase from 207 mt to 264 mt. Average total production in the subperiods 1981-85 and 1986-91 in the Kurunegala District were 347 mt and 348 mt, respectively. (The years 1987 and 1989 were not included as these years experienced severe drought). Average total production in these two subperiods in Kandy District were 85 mt and 87 mt, respectively.

As Attanayake and Wijayarathna (1986) indicate, in the light of (a) large investments that have been made towards improvement of irrigation facilities and the consequent improvements in water availability; and (b) relatively high yield levels such as in Polonnaruwa District, "a big jump" in the yield level may not be expected in these "well-watered" areas. However, it is prudent to investigate the gap between high-yielding and low-yielding farms in these areas and explore the possibility of bridging the gap. In this regard, it is very important to consider non-water factors and their management because these factors may determine yield levels when water is not a constraining factor. Also, diverting a major proportion of further investments to improve other more suitable areas which are already under rice cultivation, with the main emphasis on the cost-effectiveness of such investments, seems to be more appropriate.

TRENDS IN COST OF PRODUCTION AND PRODUCERS' PROFIT MARGINS

The changes that have occurred in the cost of cultivation of rice mainly since 1985 in different water regimes are dealt with in this section. The analysis of the cost of cultivation of rice follows an investigation of the changes in farm income that have taken place during the same period. The changes in costs and returns of rice production help evaluate the trends in the profit margins of the

rice cultivation under different water regimes. Data used are from the Department of Agriculture (DA) and it is important to reemphasize that the DA has not published its cost-of-cultivation data in 1987 and 1988 due to the unsettled situation that prevailed in the country. Consequently, 1987 and 1988 data are not included in some analyses.

Changes in the Cost of Production

The production costs under all the water regimes have increased over the years, with districts that have better water conditions showing higher costs. The farmers have spent more money on cultivation in irrigated lands irrespective of cultivation seasons. The average costs of rice cultivation during maha seasons between 1985/86 and 1989/90 under irrigation were Rs 9,173/ha, Rs 10,013/ha, and Rs 13,804/ha in Kurunegala, Kandy and Polonnaruwa districts, respectively. The respective figures for the three districts for 1981/82 maha season were Rs 7,769, Rs 7,373, and Rs 6,770. The price increases were 18, 36, and 104 percent, respectively. Under rain-fed conditions, there have been a 78-percent and a 110-percent increase in the cost of production. The lack of a reliable water source may have been responsible for the little difference in the total costs in the Kurunegala District over the years. In Kandy District, rain-fed farming seems to be more expensive than irrigated farming.

Factors Responsible for Variations

The main reason for the variations observed in the cost of production could be the technology associated with high-yielding varieties of rice and better water conditions, provided that the consequences of inflation are common for all districts. In determining the reliability of water supply in each district, the area under irrigation has been considered as the major criterion.

In spite of the low average annual rainfall and its higher variability (Table 11.1), Polonnaruwa District has the best assurance of water where the irrigated rice crop is concerned. This is because the area fed by the major irrigation systems in Polonnaruwa District is 97 percent against 20 percent in Kurunegala District. Table 11.1 gives a summary of comparisons of reliability of water supply and annual average rainfall along with data on cost of production. According to the average annual rainfall they receive, rain-fed areas can be ranked as Kandy, Kurunegala, and Polonnaruwa in descending order. These analyses show a close link between the level of investments and the assurance of water availability. Therefore, it can be concluded that, to a large extent, reliability of water supply determines the level of investments of rice production.

Table 11.1. Comparison of water status in selected districts and their average cost of production.

District	Annual average rainfall (1981-90)	Standard deviation	Area fed by different sources of water as a % of area sown in 1990			Cost of production 1989/90 (Rs/ha)
			Major Irri. Sys.	Minor Irri. Sys.	Rain	
Kurunegala	1,577	305	19.7	36.3	44	9,173
Kandy	2,601	418	22.5	40.23	37.2	10,013
Polonnaruwa	1,485	327	97.2	0.7	2.0	13,804

Attanayaka and Wijayarathna (1986) have summarized many studies which deal with the direct and indirect influence of water on rice yields. Herath (1981) points out that the lack of proper water control measures and the resulting uncertainty in water availability make it less attractive for producers to take the risk of investing in the full package of inputs recommended for the new varieties.

Risks associated with rain-fed farming in Sri Lanka stem mainly from excess or insufficiency of water. Problems associated with floods are mainly confined to the wet zone, while both wet and dry zones experience water insufficiencies during the yala season. The basic problem accompanying irrigated farming appears to be the inadequacy and unreliability of water distribution. This may happen due to inefficiencies in irrigation system performance and/or shortages in the aggregate supply from the main source of water. Inefficiency in system performance may be caused by "software" (management) or "hardware" (physical infrastructure) problems. Shortages in the aggregate supply may even lead to complete crop failures.

As Barker et al. (1985) have stated, water is a major limiting factor in rice production in the tropics where the dominant monsoon weather patterns create pronounced wet and dry seasons. Water in appropriate amounts at the correct time in the growth cycle is crucial to high rice yields. Therefore, irrigation directly influences the crop yield. In addition, there is a complementary technical relationship between irrigation and other modern inputs in terms of their effects on the ultimate crop yield. Barker (1985, p103) shows that favorable water conditions result in an upward shift in the fertilizer production and vice versa.

Also, water supply could change farmers' behavior which may have an indirect influence on yields. For instance, reliable distribution of water may lead to its increased use by some farmers. Such behavioral changes could be more prominent under small farmers' production environment because these farmers have been classified as risk averters by many researchers (Walgin 1975; Weins 1976; Herath 1981).

This implies that the effect of water distribution on the contribution of fertilizer in the derived production is not only a technical one, but also a behavioral one.

The questions central to this issues are: To what degree has irrigation been able to remove the risks faced by the small farmer? Does the favorable complementary relationship that exists between irrigation and other inputs compensate enough for the rising costs of these inputs?

The potential of high-yielding varieties could be realized only if these are grown with recommended packages of inputs such as fertilizer, water, and chemicals for control of pests and diseases, etc. Therefore, in areas with (relatively) poor water supply, farmers may not try to reach the full potential of high-yielding varieties by adhering to the recommended packages, whereas in areas with assured irrigation, farmers incur high costs for the input packages due to price escalations. Also other factors, such as farming skills, attitudes, resource endowments, etc., could influence the effectiveness of application of these inputs directly used in the production process.

Effect of Inflation

In addition to the intensification of rice production, which is usually associated with better water conditions, increases in total cost of production may have taken place as a result of several other factors. These may include the increasing rate of inflation in the country which, in turn, influences the prices of major inputs and services required for rice production. Also, replacement of certain operations by certain capital-intensive innovations could result in both increased costs and changes in the composition of the cost structure.

The rate of inflation has risen remarkably over the recent years. For instance, the year 1990 saw a sharp upsurge in the general price level. On an annual average basis the Colombo Consumer Price Index (CCPI) moved up by 21.5 percent during the year 1990. The increase on a point-to-point basis (December 1990 over December 1989) was slightly lower at 19.6 percent (Central Bank of Sri Lanka 1990). The acceleration in price change was also reflected at the primary market level with the Wholesale Price Index (WPI) registering an annual average increase of 22.2 percent between 1989 and 1990. The comparison of unadjusted cost/income data over time is not realistic owing to significant price changes that have occurred during the last few years. Such a comparison may distort the apparent trends which, in turn, would result in a misleading measurement of economic performance of the producer. Therefore, it is necessary to convert the price value to a standard for a meaningful comparison.

Index Used in Calculating Deflation

The CCPI or WPI do not seem to be appropriate deflators for costs related to agricultural production methods. And the indices based on the fixed base weights method become less efficient as the base periods get more and more remote and the input mix as well as the relative importance of individual items vary over time. Therefore, the price of the product (price offered by the private dealers, or the open-market price) is considered to be appropriate as a larger share of the production has been purchased by the private dealers compared to the government dealer, namely, the Paddy Marketing Board, which has purchased a smaller share at a guaranteed price. The Department of Agriculture gives selling prices for respective districts. This method, which was introduced by Barker (Barker et al. 1985), has been used in several other studies (Attanayaka and Wijayaratna, 1986; Abeysekara 1986).

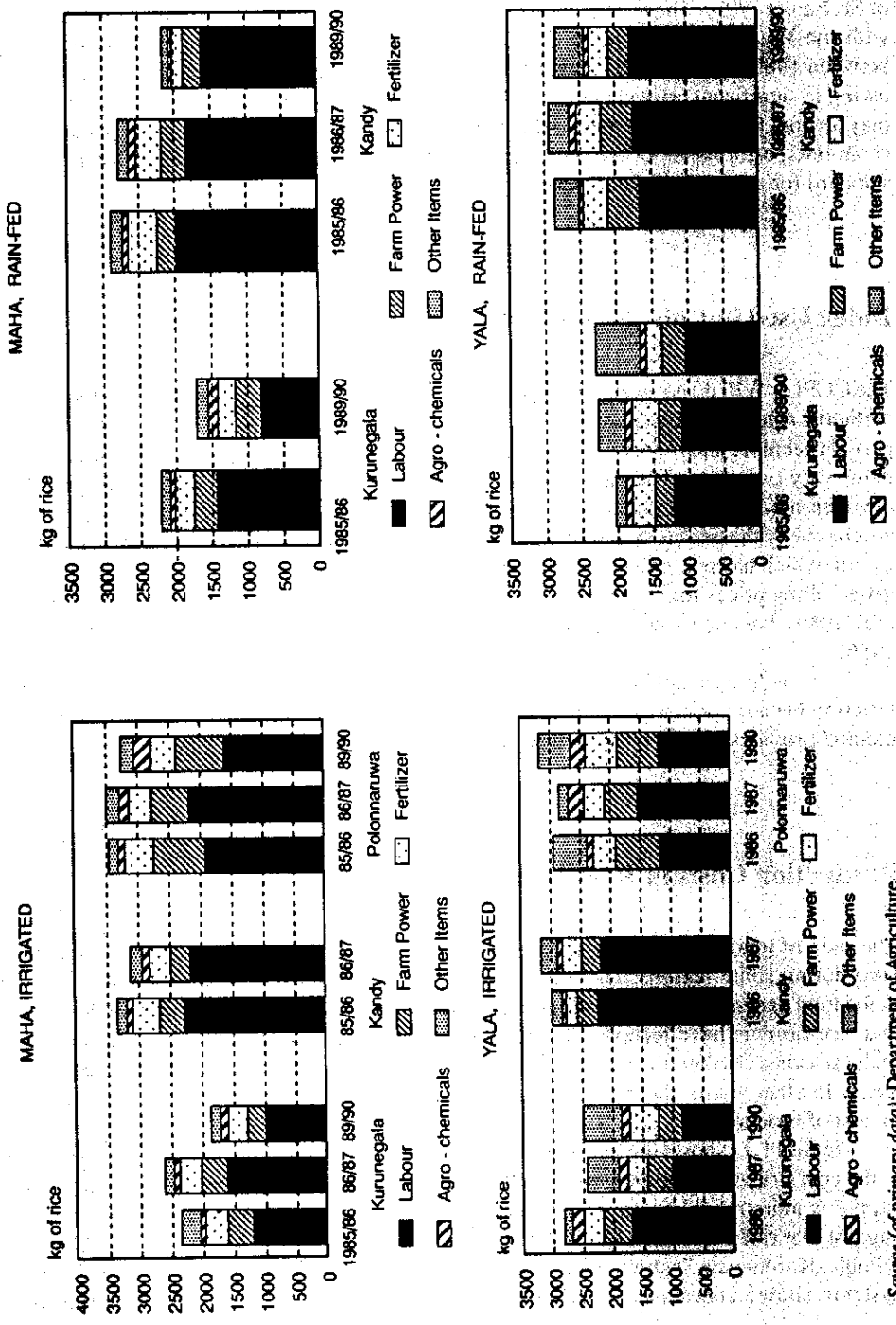
This method cannot be considered as entirely compensating for price changes stemming from inflation because prices of rice may change in relation to other items. Despite this limitation the method provides a more clear picture of the price changes over the years.

Production Costs in Real Terms

The ratio of total cost of production to market price of rice tends to increase in all the districts, at least during some seasons. The increase in the cost of production implies that the rate of change in the total expenditure has been higher than that of producer price of rice over the years. The price that rice farmers have received during recent yala seasons has been higher than that during the maha seasons. Further, in yala seasons, there is an increasing trend in the cost of production in real terms. In other words, the rise in the market price of rice has failed to compensate for the increase in cost of production.

Figure 11.11 shows the total cost of production in real terms and the share of major input items in the cost structure. A more prominent trend can be seen in Polonnaruwa District where the water supply is more reliable compared to the other two districts. The results in Polonnaruwa District suggest that rice cultivation has become capital-intensive in areas where the water supply is more reliable. Kurunegala District, which has only 20 percent of rice lands belonging to major irrigation systems, shows a decreasing trend in the costs except for yala seasons under rain-fed conditions.

Figure 11.11. Cost of production in rice equivalents.



Source (of primary data): Department of Agriculture.

Paid-Out Costs

Paid-out costs can be roughly calculated by deducting the value of family labor from the total cost of production. As Table 11.2 shows, the total paid-out cost seems to be higher in areas where rice is produced with a reliable supply of water. Irrigated areas in Polonnaruwa District have the highest paid-out-cost values.

Kandy District, where rain-fed areas have a reliable water supply compared to Kurunegala District, records values of paid-out costs which are higher than those for the Kurunegala District.

Table 11.2. Total paid-out cost for rice production under different water regimes (in kg of rice).

Season	Kurunegala		Kandy	Polonnaruwa	
	Irrigated	Rain-fed	Irrigated	Irrigated	Rain-fed
1985/86 maha	2,370	2,201	3,366	3,414	2,913
1986/87 maha	2,588	NA	3,067	3,463	2,792
1989/90 maha	1,825	1,670	NA	3,249	2,180

Note: NA = Not available

Cost Structure and Its Relative Composition

Figure 11.11 gives the composition of production costs during both yala and maha seasons under irrigated and rain-fed conditions in all the three districts under consideration. Labor, farm power, fertilizer, and agro-chemicals occupy about 90 percent of the total cost of production. Of the items that are responsible for a major share of the cost of production, labor accounts for the largest portion irrespective of the season or the district concerned. The share of the labor component is about 50 percent.

Though an increase has been registered in the total cost of production, a clear trend in the composition of the structure cannot be identified in the period concerned. However, the composition of the cost structure is characterized by the specific situation in the districts. For instance, the portion that has been occupied by farm power has always been higher in Polonnaruwa District. Since the majority of the population draws its main income from rice cultivation, there is relative scarcity of labor in Polonnaruwa District during peak demand periods. Consequently, farmers hire machines to supplement a considerable portion of labor in the cultivation process. Despite the higher percentage spent on farm power, labor is responsible for a higher percentage of cost of production in the irrigated areas. Farmers in the Polonnaruwa District spend about 1,244 kg rice equivalents on hired labor compared to 352 kg rice equivalents spent by farmers in the Kurunegala District in maha seasons with irrigation facilities.

Table 11.3 shows that labor requirement in rain-fed areas in Kurunegala District is lower than that of its irrigated areas, whereas in Kandy District, rain-fed areas require more hired labor for rain-fed cultivation. The physical setting and its limitations for the use of machinery may necessitate farmers in Kandy District to hire more labor. The necessity to use more labor is clear since farmers in Kandy District have spent only a small portion on farm power.

There is no clear increase in the expenditure on fertilizer over the years. In fact, the proportion spent on fertilizer under rain-fed conditions tends to decrease over years in Kurunegala and Kandy

Table 11.3. Hired labor requirement in rain-fed areas of districts as a percentage of the hired labor requirement of their irrigated areas.

Season	Kurunegala	Kandy	Polonnaruwa
Maha			
1985/86	44	92	NA
1986/87	NA	60	NA
1989/90	65	NA	NA
Yala			
1986	12	119	NA
1987	90	51	NA

Note: NA = Not available

districts except for 1989/90 maha in Kurunegala. The absence of a clear increase in the expenditure on fertilizer is rather alarming since the price of fertilizer has increased considerably over the years. This is because it indicates that farmers are not prepared to spend more on fertilizer at the cost of other inputs which should be used in the specific amounts recommended by the Department of Agriculture.

Major Contributors to the Increase in Factor-Costs

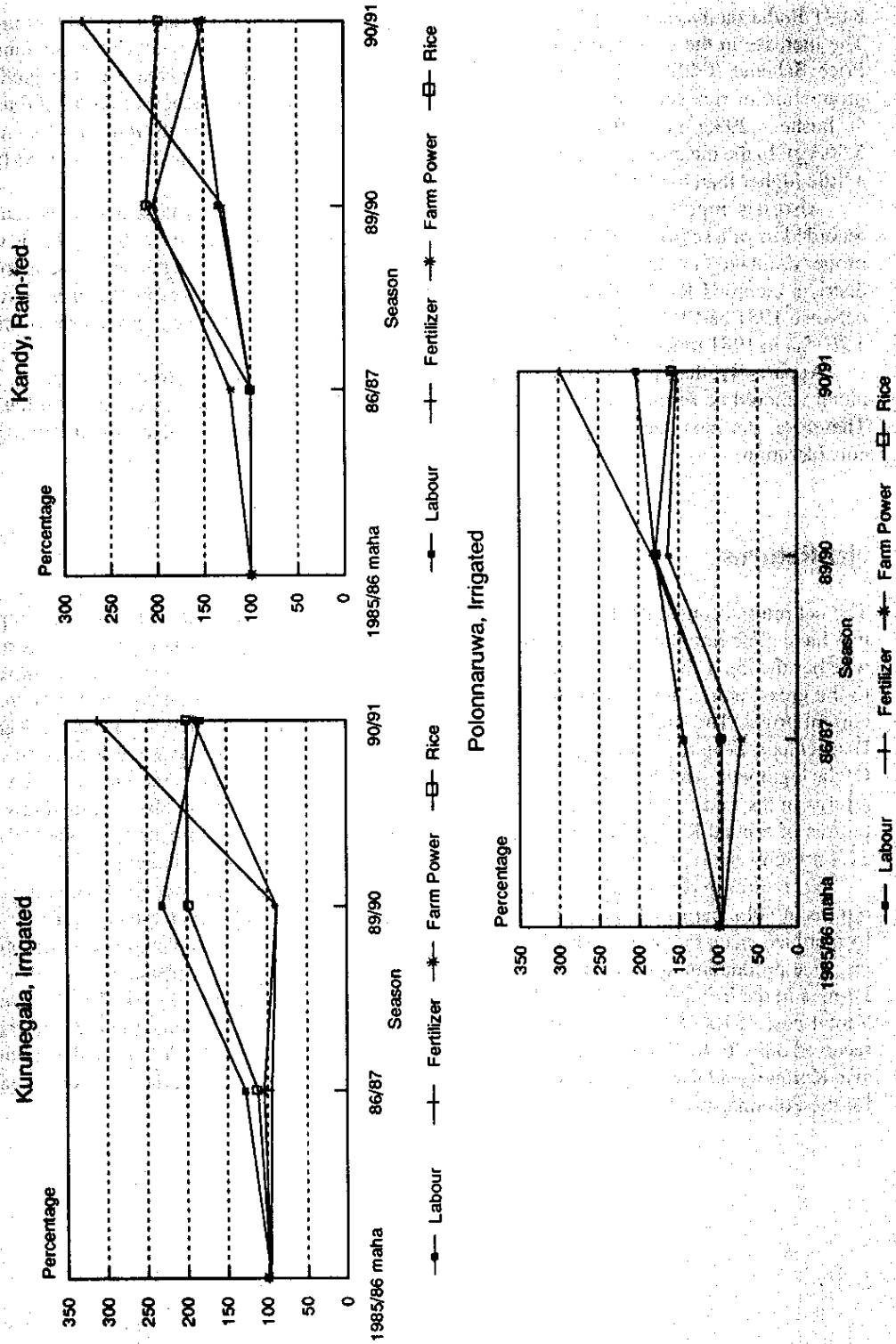
Of the four major items that have been identified as contributing to a major share of production costs, labor and fertilizer seem to be the most significant components in pushing up the total cost of production. The impact of farm power on increasing costs also could be considered as substantial but it is not as consistent as those of labor and fertilizer.

Figure 11.12 gives the price changes in labor, fertilizer and farm power along with the market price of rice in relation to the base year 1985/86. Here, the average fertilizer price was calculated by dividing the values of basal dressing, urea, and Top Dressing Mixture. The price of fertilizer has almost trebled between 1985/86 maha and 1990/91 maha in all the districts under consideration. The prices of labor and farm power have increased by 50 percent to 100 percent during the same period. For instance, the price of fertilizer that stood at Rs 3.07 per kg in 1985/86 in Polonnaruwa District increased up to Rs 9.28 (a 302 percent increase) by the 1990/91 maha season. The market price of rice that stood at Rs 3.32 per kg in 1985/86 maha in Polonnaruwa District increased only up to Rs 5.18 (a 56 percent increase) by the 1990/91 maha season.

Changes in the Producer Profit Margins

On the basis of primary data of the Department of Agriculture, gross income of the farmers has increased remarkably in each water regime. The increases of the gross income between 1981/82 maha season and 1989/90 maha season were about 12,500 Rs/ha and 12,000 Rs/ha, respectively, in the irrigated areas in both Kurunegala and Polonnaruwa districts. The gross income per cultivated ha had increased by Rs 2,850 in Kandy District between 1981/82 maha and 1986/87. Similarly, farmers in rain-fed areas in Kurunegala and Kandy districts recorded 6,674 Rs/ha and

Figure 11.12. Price changes in inputs and outputs.



8,041 Rs/ha increases in gross returns, respectively between 1981/82 maha and 1989/90 maha. The increase in the gross return is mainly due to the increase in the price under the Guaranteed Price Scheme (GPS). This is because there has been no significant increase in the yield or production of rice since the mid-1980s. The GPS price of rice which stood at Rs 40.00/bushel (1 bushel = 29 kg) in 1990 rose to Rs 110/bushel by 1990 (a price increase from Rs 1.82/kg to Rs 5.00/kg). In the meantime, the price received by the farmers or the farm gate price has always been a little higher than the GPS price.

Also, it is important to look at the performance of the rice crop during yala seasons. The returns recorded in yala seasons will help make decisions on growing nonrice crops in the rice lands with proper drainage facilities. The farmers in the irrigated areas in the Kurunegala and Polonnaruwa districts recorded Rs 21,009/ha and Rs 18,198/ha (respectively) increases in the gross returns between 1981 and 1990. The farmers in the Kandy District increased their gross returns from Rs 5,207/ha in 1981 to Rs 10,238 in 1987.

Apparently, the gross returns from the rice crop seem to have increased over the years. The picture should be further studied taking the changes that have taken place in costs and inflation. Therefore, the next section will deal with the net returns, taking the impact of inflation into consideration.

Net Returns

The net returns constitute the difference between the gross returns and the value of all the inputs that have gone into the rice production including family labor. This indicator gives an idea as to whether the inputs have been increasing at the same rate as the farm gate price of rice. Compared to the gross returns, net returns per unit of land have increased only marginally even in terms of current prices. The situation is further critical when real values are considered. Farmers in Kandy District have been recording very low net returns under both the irrigated and rain-fed conditions. Of the eight yala seasons since 1981 (except 1988, and 1989), three seasons recorded negative net returns in the rain-fed areas in the same district. The areas under irrigation also recorded low net returns of around Rs 2,000/ha with one season experiencing negative net benefits as well. Table 11.4 presents net returns in terms of current price and real values (rice equivalents).

Net returns in Kurunegala and Polonnaruwa districts have been at a higher level. Though gross returns in Polonnaruwa District are higher than those of Kurunegala District, the net returns in the former have been rather low. This is because in the Kurunegala District the inputs that have gone into rice production are less than those of the Polonnaruwa District. For instance, in 1990 yala, farmers in the irrigated areas in the Kurunegala District received net returns of Rs 15,247 against a total cost of Rs 16,005 (Benefit/Cost ratio $[B/C] = 1.95$) while the Polonnaruwa counterparts received only Rs 10,479/ha against a total cost of Rs 18,718 ($B/C = 1.45$). Under rain-fed conditions also Kurunegala District recorded somewhat attractive results (comparative data are not available for the Polonnaruwa District).

Table 11.4. Changes in net returns.

Water regime and season	Kurunegala District		Kandy District		Polonnaruwa District	
	Current price (Rs/ha)	Real value (kg of rice)	Current price (Rs/ha)	Real value (kg of rice)	Current price (Rs/ha)	Real value (kg of rice)
RAIN-FED						
<i>Yala</i>						
1986	3,018	809	1,025	304	NA	NA
1987	3,060	836	-1,309	384	NA	NA
1990	7,665	908	1,874	284	NA	NA
<i>Maha</i>						
1985/86	7,130	1,654	445	136	NA	NA
1986/87	NA	-313	92	NA	NA	
1989/90	6,999	1,167	5,899	838	NA	NA
IRRIGATED						
<i>Yala</i>						
1986	5,204	1,591	2,224	652	3,173	909
1987	4,875	1,304	476	142	4,132	1,126
1990	15,247	1,875	NA	NA	10,479	1,648
<i>Maha</i>						
1985/86	6,561	2,116	2,193	941	4,966	1,496
1986/87	6,571	1,861	272	83	3,427	1,045
1989/90	13,361	2,112	NA	NA	8,484	1,473

Note: NA = Not available

Comparison with Nonrice Crops

It is interesting to note that nonrice crop cultivation in these areas yields significantly high levels of profit margins while rice farmers are facing a situation of eroding returns to a unit investment. A comparison of production costs and returns according to various factors of production for cultivation of rice and chili in Kurunegala District is given in Table 11.5. (The Department of Agriculture has not published data on nonrice crops for the other two districts.) Data available suggest that returns to all factors of production are higher in chili cultivation while the most striking indicator seems to be the total profit margin per unit of land of chili over that of rice. Also, nonrice cultivation eases the problem of underemployment since most nonrice crops require labor throughout the season. Another way of comparing the performance of the rice crop with those of nonrice crops is through their water productivity, which can be calculated in a crude way as returns to a unit of water that was consumed by the crop. Table 11.5 shows that in terms of water productivity, the chili crop records remarkable high yields over the rice crop.

Table 11.5. Production costs and returns to selected factors of production for rice and nonrice crops under irrigated conditions in Kurunegala District, 1990 yala.

	Rice	Chili
Cost of production (Rs/ha)	16,005	25,262
Gross returns (Rs/ha)	31,253	79,627
Net returns (Rs/ha)	15,247	54,365
Labor requirement (days)	160	320
Profit per labor day	95	170
Profit per Rs 100 investment (Rs)	95	215
Water productivity (Rs/m ³)	1.89	5.10
Assumed water requirement* (m ³)	16,500	15,600

Note: Water productivity = Gross returns/ Total water requirement

* Water requirement was assumed using the data available for other study locations since specific data are not available for Kurunegala District.

POLICY IMPLICATIONS

Rice cultivation will continue to play a vital role in the Sri Lankan economy. Investments in irrigation and associated technologies such as high-yielding seed varieties and fertilizer, together with management inputs had contributed to the significant increase in rice production and productivity in the past. The area cultivated to rice and the national average of rice yield had reached their peak levels by the mid-1980s. Apparently, 1985 was a turning point: key determinants of total production such as yield level and area cultivated did not show clear rates of growth under any one of the three regimes of water considered in the analysis. The cropping intensity, which had been stagnating over a longer period, also did not show any significant improvement. It is clear that unfavorable weather conditions and certain other "external factors" have contributed to this state of affairs. The study did not analyze the possible contributions of declining soil fertility or increased incidence of pests and disease attacks, etc. on the recent decline in the growth rates of production and productivity. It would, however, be difficult to quantify such contributions to rice production during the period 1985-91, because: a) cultivation in many areas has been affected by such external factors as unfavorable weather conditions and civil disturbances; and b) the time period under consideration is too short to establish such trends, especially due to the lack of a proper data set including "controlled" conditions.

The rise in the market price of rice has failed to compensate for the increase in the cost of production. Rice cultivation, especially in "well-watered" areas has become a more capital-intensive venture. The price of fertilizer for instance, has trebled between 1985 and 1991, and costs of labor and farm power have increased 50-100 percent in the three districts included in the sample. The market price of rice, on the other hand, had increased by about 55 percent during the reference period (Figure 11.12). The net returns per unit of land in real terms have not shown a significant improvement in any one of the areas studied.

In the context of uncertain (world) prices for rice, declining growth rates of production and eroding profit margins, it would be prudent to analyze the potential for future increments in

productivity of scarce factors of production and increasing cropping intensity, while checking the cost of production which is an equally important factor.

The analysis in this study did not include an in-depth enquiry into the differences between (a) production areas such as different irrigation schemes or (b) farms in the same area. For instance, there is a *need to analyze the gap between the high-yielding farms and low-yielding farms, in similar production systems*. Both water and non-water factors may be responsible for such gaps. And, such gaps, perhaps, may be reduced by low-cost management techniques.

In the long term, research may be conducted to explore the possibility of raising the technical ceiling of crop yields. Research into appropriate crop management techniques should also investigate the comparative long-term productivity of the continuous cropping of rice versus alternative rice-based cropping patterns. Providing crop rotation in a rice cropping system helps to maintain or regenerate soil fertility, reduce weeds and pest buildup, and provide more diversified options to sustain farm incomes (Westcott and Mikkelsen 1988). Grain legume crops such as mungbean or cowpea, leguminous green manures, or vegetable crops may be particularly suitable rotation crops with rice.

Improving yields through increasing input-use efficiency. In addition to improved water management, other input-saving technical changes can also be considered. These may take several forms and the following are a few examples: integrated pest management, integrated nutrient management, direct seeding techniques in place of transplanting, and more efficient water use.

Cropping intensity. Nearly one half of Sri Lankan rice lands are cultivated to anything but a single rice crop per year. Is there a potential for increasing the intensity of cultivation on these lands? Technically, double cropping of rice on the favorable lowland areas is possible with early maturing varieties and more determined research on the management constraints. However, the real potential for increasing cropping intensities lies with the expansion of nonrice crop production in irrigation systems.

However, to be successful in irrigation systems that have a diversified cropping pattern, collective action is needed to: i) ensure adequate water supply; ii) regulate timing of water supply; and iii) prevent excess water for the nonrice crops. The timing of water flow for nonrice crops is different from that of the rice crop and in-season regulation of timing of water is important. Also, the water flow has to be regulated to prevent excess water into the nonrice crop lands. Therefore, the necessity for collective action for water control is more important in irrigation systems where nonrice crops are grown.

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