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A selection of papers presented
at Internal Program Reviews

INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE

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Foreword

THE MANAGEMENT OF irrigated land to sustain agricultural productivity for the world today and for generations to come, is the major concern of the International Irrigation Management Institute (IIMI). IIMI's mission is to strengthen national efforts to improve and sustain the performance of irrigation systems in developing countries through the development and dissemination of management innovations. IIMI,which is headquartered in Sri Lanka and which conducts programs in a significant number of countries in Asia and Africa, is one of a set of international agricultural research centers supported by the Consultative Group on International Agricultural Research (CGIAR).

IIMI has studied the problems that developing countries must confront in managing their irrigation systems. It has carried out its work through field research in several different countries and through programs of thematic research that transcend national boundaries. Its research work is now bearing fruit in terms of research results. This volume contains the first set of scientific findings to be published by IIMI in a consolidated form. The set has been derived from the presentations at IIMI's annual Internal Program Reviews for 1989 and 1991 and from work undertaken during 1991.

The document first focuses on the financial and human resource implications of management strategies to render the development, operation, and maintenance of irrigation systems more efficient and effective. The volume then focuses on improvements to the management of irrigation systems and the relationships with the ultimate beneficiaries — the farmers. The third section addresses emerging issues deriving from the first successes of IIMI's research, for example, in conjunctive management of groundwater and surface irrigation systems; the results of experience in tackling problems arising from salinization, waterlogging, and connected issues are dealt with in some depth. Lastly we focus on performance, principally on mechanisms and innovations which have been empirically tested for reliability and which hold out promise of better performance in the irrigated sector.

All the studies presented in this volume are the result of collaborative research efforts that involve both the specific chapter authors as well as a large number of individuals in client and partner agencies. We are grateful to all our collaborators for their many important contributions, as well as to the members of IIMI's Support Group who have provided the financial assistance that has made the research reported in this volume possible.

We hope that this volume of IIMI's research findings will appeal to a wide section of the irrigation and water development community, including policymakers, managers, irrigation researchers, and development scientists around the world.

Readers are encouraged to contact IIMI on any aspect of the research activities presented here.

Roberto Lenton
Director General
International Irrigation Management Institute
October 1991

PART 1

Financial and Human Resources

CHAPTER 1

Irrigation Investment Trends in Sri Lanka: Implications for Policy and Research in Irrigation Management

Masao Kikuchi

In association with Douglas J. Merrey, R. Sakthivadivel and P.B. Aluwihare

EVERYONE AT IIMI is firmly confident of the importance of improving irrigation management and so, to a lesser extent, are the policymakers associated with the irrigation sector in Sri Lanka and elsewhere in the third world. On what grounds is this confidence based? All of us strongly believe that irrigation management improvement will have a high economic payoff, but how large is the economic potential for such improvements? No one doubts the need for research to improve irrigation management, but how profitable is it to invest in such research?

Our confidence stems mainly from the fact that the existing irrigation schemes in the third world, many of which have been constructed in the last few decades with huge capital investments, perform below expectations. The answers to the questions above therefore hinge upon the size of the gap between actual performance and expected, or maximum attainable, performance. We believe this gap to be substantial rather than marginal and, using the irrigation sector in Sri Lanka as an empirical example, we try in this paper to substantiate a "material" basis for this belief.

Some qualifications need to be made. The first concerns the dimension or domain of the issue. Any research in irrigation management begins with the belief that such research is important, and looks into the process of irrigation management with a view to enhancing the performance of irrigation systems. The issue dealt with in this paper precedes this process, having nothing to do with "management" per se. In terms of IIMI's strategy, it is related to the component of "Objectives/National Irrigation Policies," and not with the "Process" components. However, since this study tries to evaluate the investment performance of different types of irrigation projects, its findings give not only direct support, but, to a certain extent, direction for irrigation management research.

The second concerns the shift of the irrigation sector in Sri Lanka, as in many other countries in the Asian tropics, from a "construction" phase to a "management" phase. This shift has had to occur simply because the management side of irrigation projects has been grossly neglected or forgotten during the "construction" phase in Asia, leaving huge potentials to be exploited by management improvements. In other words, these two phases are not necessarily mutually exclusive. Such a dichotomy in

phasing could be misleading in some countries, such as some parts of Africa, where potentials for irrigation construction still exist. In such cases, these two phases must go together.

In what follows, we first summarize the major findings of our research and then spell out some implications for policy and research on irrigation management. This paper draws heavily on Aluwihare and Kikuchi (1991).

RICE PRODUCTION AND IRRIGATION DEVELOPMENT IN SRI LANKA

Irrigation is a critical input in rice-based agriculture in monsoonal Asia. This is the case in Sri Lanka, even though the climatic conditions and historical background specific to the country make the process of irrigated agriculture development somewhat unique. First, let us briefly observe the history of rice production and irrigation development in Sri Lanka and identify the stage that irrigated agriculture has reached there.

Sri Lanka is divided into two significantly different climatic zones; the wet and dry zones. A distinctive feature of the dry zone as an agricultural region is that land is not a productive resource unless it is provided with water. Without irrigation water, the only possible cultivation is very extensive *chena*, i.e., slash-and-burn or shifting cultivation. In the wet zone, the adequate rainfall and its relatively even distribution between seasons make rain-fed rice production quite possible. Despite an ancient civilization based on irrigated lowland agriculture, the dry zone had been nearly deserted for centuries until the late 19th century, the population being concentrated in the wet zone. The process of irrigation development in Sri Lanka in the last several decades has consisted of major colonization (settlement) projects, mainly in the dry zone.[1]

Changes in the total rice land area by type of irrigation in the country are summarized in Table 1.1. The total irrigated rice land area increased from 253,000 ha in 1950 to nearly half a million ha in 1985; 90 percent of this was brought about by an increase in the irrigated land area under the major irrigation systems which are situated almost exclusively in the dry zone. As a result, the proportion of irrigated area under major irrigation systems, either in the total irrigated rice land or in the total rice land, has virtually doubled in the last 35 years. Since newly created irrigated lowland areas have been almost exclusively devoted to rice production, this rapid development of dry-zone major irrigation systems has resulted in rapid increases in the area planted to rice in the *maha* (wet) and *yala* (dry) seasons in the dry zone (Table 1.2). Excluding the

[1] This is a unique feature of irrigation development in Sri Lanka. In other densely populated Asian countries, irrigation development has mainly consisted of providing existing rain-fed lowland with irrigation facilities.

area under minor irrigation systems and rain-fed areas in the dry zone for the period 1980 to 1985, the area planted to rice has increased regardless of zone, type of irrigation, or season. However, the most significant increases have been in the major irrigation systems in the dry zone.

Table 1.1. Rice land area by type of irrigation, irrigation ratios, and cropping intensity for selected years, Sri Lanka.[a]

	Rice land area (1,000 ha)						Irrigation ratio			Cropping intensity[c]	
	Irrigated[b]				Rain-fed	Total				Total	Major irrigation
	Major irrigation (i)	Minor irrigation (ii)	Lift irrigation (iii)	Total (iv)	(v)	(vi)	i/iv %	i/vi %	iv/vi %	%	%
1950	90	163	-	253	157	411	36	22	62	107[d]	118[d]
1955	119	168	-	287	162	449	41	27	64	108	112
1960	136	171	-	308	171	479	44	28	64	120	126
1965	161	174	0	336	184	520	48	31	65	118	130
1970	193	187	2	382	201	583	51	33	66	124	127
1975	232	182	3	417	215	630	56	37	66	119	110
1980	272	184	4	460	221	682	59	40	67	125	123
1985	305	186	4	495	220	715	62	43	69	123	129

[a] Five-year averages centering on the years shown.

[b] Irrigated asweddumized land area. Major irrigation refers to the irrigation systems with a command area of 81 ha (200 acres) or more, and minor irrigation to those with less than 81 ha of command area.

[c] Yearly cropping intensity = total area planted per year divided by the asweddumized area. The total cropping intensity includes lands in all the categories.

[d] Three-year average for 1950-53.

Source. Aluwihare and Kikuchi (1991)

This development in irrigation infrastructure paved the way for the successful introduction of seed-fertilizer technology in rice production. As shown in Table 1.3, the fertilizer use per hectare of rice planted began to rise in the late-1950s as the Old Improved Varieties were being adopted by rice farmers. By the mid-1980s, virtually all rice planted consisted of improved varieties. Parallel to this, fertilizer intensity increased tremendously, reaching a level more than 100 kg/ha. It is noteworthy that the process of "seed-fertilizer revolution" began much earlier in Sri Lanka than in other countries in the Asian tropics. This can be partly explained by the fact that Sri Lanka

Table 1.2. Total area planted to rice by zone and by type of irrigation, for selected years, Sri Lanka.[a]

	Total	Dry Zone						Wet Zone
		Major irrigation			Minor irri gation	Rain-fed	Total	
		Maha	Yala	Total				
	1,000 ha							
1952	451.1	53.6	48.3	101.9	66.6	82.2	250.7	200.4
	(100)	(12)	(11)	(23)	(15)	(18)	(56)	(44)
1960	577.2	90.1	66.5	156.6	103.3	109.4	369.3	207.9
	(100)	(16)	(11)	(27)	(18)	(19)	(64)	(36)
1970	721.4	133.8	86.5	220.3	126.1	135.0	481.5	239.9
	(100)	(18)	(12)	(30)	(17)	(19)	(67)	(33)
1980	855.1	199.3	113.13	12.4	139.8	150.3	602.7	252.4
	(100)	(23)	(13)	(35)	(16)	(17)	(70)	(30)
1985	874.6	222.4	147.9	370.8	130.3	133.3	634.9	239.7
	(100)	(25)	(17)	(42)	(15)	(15)	(73)	(27)
Growth Rate (%) :								
1952-60	3.1	6.7	4.1	5.5	5.6	6	5.0	0.5
1960-70	2.3	4.0	2.7	3.5	2.0	2.1	2.7	1.4
1970-80	1.7	4.1	2.7	3.5	1.0	1.1	2.3	0.5
1980-85	0.4	2.2	5.5	3.5	-1.4	-2.4	1.0	1.0
1952-85	2.0	4.4	3.4	4.0	2.0	1.5	2.9	0.5

[a] Five-year averages centering on the years shown. Figures within parentheses are percentages.

Source: Aluwihare and Kikuchi (1991)

was endowed with a better irrigation infrastructure at the onset of agricultural development after independence; the irrigation ratio in 1950 was as high as 62 percent for cultivated rice fields (Table 1.1) and 48 percent for rice cropped area (Table 1.3).[2] On the one hand, such a favorable initial irrigation infrastructure provided a strong incentive for national agricultural research institutions to develop improved rice varieties. On the other hand, the successful development of seed-fertilizer technology, by raising the payoff to investments in irrigation, increased the incentive for the government to develop the irrigation infrastructure further. Such a dynamic interaction between the irrigation infrastructure and the seed-fertilizer technology may well have fuelled the rapid development of irrigation in the dry zone.

[2] Such high irrigation ratios at the start of agricultural development after independence are another unique feature of irrigation development in Sri Lanka when compared with other countries in the Asian tropics.

Table 1.3. Fertilizer input for rice production per hectare, irrigation ratio, and rice variety ratio, for selected years, Sri Lanka.[a]

	Fertilizer input		Irrigation ratio[c]	Variety ratio[d]		
	Total[b] (N+P+K) (kg/ha)	Nitrogen (kg/ha)	(%)	Traditional Varieties (%)	Old Improved Varieties (%)	New Improved Varieties (%)
1952	2.6	1.7	48	100	-	-
1960	13.8	8.3	57	87	13	-
1970	53.2	32.9	60	32	59	9
1980	85.2	57.2	62	13	15	72
1985	111.8	75.5	66	2	6	92

[a] Five-year averages centering on the years shown.
[b] Nutrient content (three major elements) of the fertilizer.
[c] Irrigated area planted to rice/total area planted to rice.
[d] Percentage of rice variety planted

Source: Aluwihare and Kikuchi (1991)

As a result, the country has experienced dramatic increases in rice production during the last four decades (Table 1.5). Immediately after independence, the country was producing only 40 percent of its total rice requirements, and the remaining 60 percent was imported. By 1985, the rate of self-sufficiency in rice had reached a level of more than 90 percent. Self-sufficiency in rice is now within sight for Sri Lanka.

Table 1.4. Rice production, rice imports, and rate of self-sufficiency in rice for selected years, Sri Lanka.[a]

	Domestic rice production[b] (x)	Rice imports[b] (y)	Self-sufficiency in rice (%) $\frac{x}{x+y}$
	1,000 metric tons		
1951	428	633	40
1955	613	661	48
1960	864	739	54
1965	989	710	58
1970	1,409	523	73
1975	1,400	602	70
1980	2,062	271	88
1985	2,455	220	92

[a] Five-year averages centering on the years shown.
[b] In rough rice equivalent

Source: Aluwihare and Kikuchi (1991)

Using the rice fertilizer response functions by variety and irrigation condition, we arrive at the following rough breakdown of the rice production increase between 1952 and 1985 into the three major contributing factors:

		(1,000 mt)	(%)
Total rice production increase		2,087	100
Increase due to:	Variety	861	41
	Fertilizer	561	27
	Irrigation	665	32

Irrigation development since independence has thus played a pivotal role in increasing the total rice production through increasing both the area planted and the land productivity. Now that the longstanding national policy target of self-sufficiency in rice is almost attained, the development pattern of the peasant agriculture sector in Sri Lanka, which has primarily been based on the dry-zone colonization, has reached a turning point.

TRENDS IN IRRIGATION INVESTMENTS

As outlined above, irrigation development in Sri Lanka has been attained through massive investments. Public investments in the post-independence period are summarized by type in Table 1.5, and their trends in terms of five-year moving averages are shown in Figure 1.1. Irrigation investments are grouped into three categories: new construction, rehabilitation, and operation and maintenance (O&M).

"New irrigation construction" refers to projects aimed at the construction of modern irrigation systems. In the dry zone, there are still many abandoned tanks dating from the time of the ancient Sinhalese kingdoms. In some cases, a modern system was created just by restoring the ancient system. In other cases, a new reservoir, together with new canal networks and new command areas, was constructed. The former may be called "restoration," and the latter "new construction." However, since even "new construction" projects usually include in their new command areas some old small tank systems, it is rather rare to find an entirely "new" irrigation construction project in the dry-zone setting. Included in the "new" construction are all those projects that are not categorized as "rehabilitation," which is defined as the restoration of deteriorated, but still functioning, irrigation systems to their original capacity, or their modernization.

The investments for new irrigation construction here include only those related to the development of the irrigation infrastructure, such as reservoir, canal, rice field, and road construction. Settlement-related investments, as well as such overhead costs as the personnel emoluments at the headquarters of the irrigation construction related

Table 1.5. Irrigation investments in Sri Lanka, in 1986 prices, by type of investment, and their share in the government budget and the total public investment, 1950-88.[a]

	Irrigation investments				Share of the total irrigation investment in	
	New construction[b]	Rehabilitation[c]	Operation and maintenance[d]	Total	Government budget	Total public investment
	Rs million in 1986 prices				%	
1950	907	-	34	941	8	37
	(96)	-	(4)	(100)		
1955	859	-	38	897	6	29
	(96)	-	(4)	(100)		
1960	601	-	121	723	3	19
	(83)	(17)	(100)			
1965	619	-	62	681	3	15
	(91)		(9)	(100)		
1970	994	-	78	1,071	3	16
	(93)		(7)	(100)		
1975	1,116	5	127	1,248	2	13
	(89)	(1)	(10)	(100)		
1980	3,023	225	137	3,385	6	21
	(89)	(7)	(4)	(100)		
1985	2,770	451	154	3,375	6	18
	(82)	(13)	(5)	(100)		
1988	1,676	308	102	2,086	3	na
	(80)	(15)	(5)	(100)		

[a] Five-year averages centering on the years shown. Figures within parentheses are percentages. na = data are not available.

[b] Investments for constructing new systems or restoring old abandoned systems. Only irrigation-infrastructure-related investments, such as tank and canal construction, are included.

[c] Investments for major rehabilitation and modernization of existing systems.

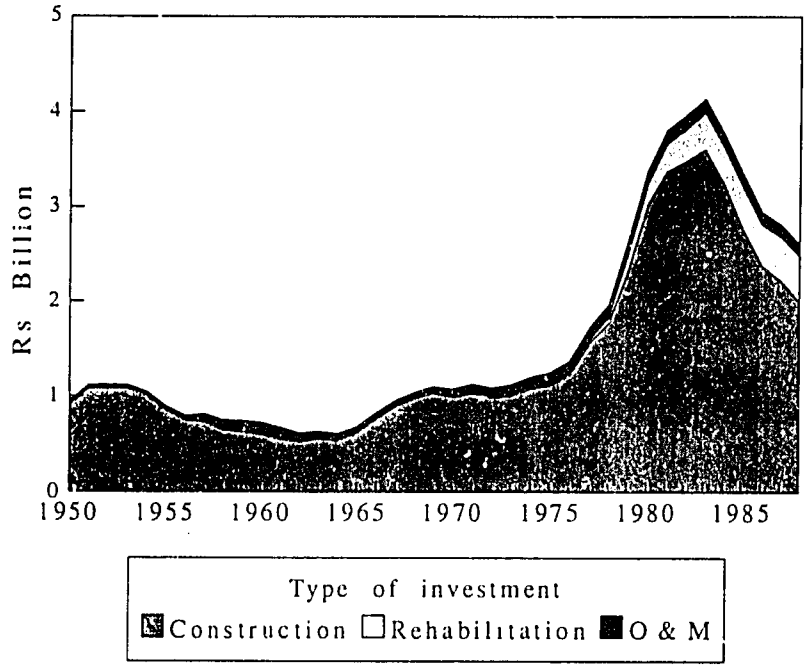
[d] Not including overhead costs such as personnel emoluments or administrative expenditures.

Source: Aluwihare and Kikuchi (1991)

agencies, are not included in the new irrigation construction investment.[3] Likewise, the rehabilitation investment and O&M expenditures are defined as not including general and administrative overhead costs.

[3] There have been several multipurpose projects concerning not only irrigation but also hydroelectric power generation. For these projects, the investment costs common to both purposes, such as the reservoirs, are apportioned to each purpose in the ratio of the benefits expected from each purpose according to the project appraisal reports.

Figure 1.1. Changes in irrigation investments in Sri Lanka, five-year moving averages, 1950-86, in 1986 prices.



Source: Aluwihare and Kikuchi (1991)

Several points are to be noted in Table 1.5 and Figure 1.1. First, irrigation, and particularly new irrigation construction, have been by far the most important investment opportunity in the country. New construction investment accounted for 96 percent of the total irrigation investments in the early-1950s, and irrigation investments as a whole took nearly 40 percent of the total public investments or nearly 10 percent of the government budget during that period. As the economy developed, the share of total irrigation investments in the total public investments declined towards the mid-1970s. However, around 1980, the total irrigation investments suddenly rose again to constitute more than 20 percent of the total public investments.

Second, new irrigation construction has been the dominant type of irrigation investment, and the long-term trend of new construction investments has been upwards. Third, however, this type of investment has experienced distinct short- to medium-term fluctuations. Three peaks, or investment spurts, can be discerned. During the periods between these peaks, new construction investment decelerated. The third peak was particularly high, but new construction investment began to decline sharply after this peak.

Fourth, rehabilitation investments began in the mid-1970s and have rapidly increased their share in the total irrigation investments since then. The share rose to more than 10 percent of the total irrigation investments by the mid-1980s. The first

modern irrigation rehabilitation project in Sri Lanka was the Tank Irrigation Modernization Project (TIMP), started in 1976, which was followed by several other major rehabilitation projects. In addition to these, many water management improvement projects have been initiated since the late 1970s.

Last, expenditures for irrigation system O&M have been a minor component of the total irrigation investment. More importantly, the share of O&M expenditures in the total irrigation investments has not shown any steady increase over time. In spite of the large increase in the irrigated land area under major irrigation systems, its share in the total irrigation investments remained as low as 4 percent in the 1980s.[4] This suggests that the maintenance of the existing irrigation systems has remained inadequate, resulting in the low performance of the systems and endangering their long-term sustainability.

These observations on past investment trends in irrigation raise some interesting questions. Why have such huge investments been made for new irrigation construction? What were the factors that caused the fluctuations in new construction investments? Will there be a fourth peak in new construction investments after the third one in the 1980s? Why have rehabilitation/water management improvement projects become important since the late 1970s? Answers to these questions reveal a basic change in emphasis in the development of the irrigation sector in Sri Lanka — the shift from the construction phase to the management phase.

CONSTRUCTION PHASE

Long-Term Trend

Investments in new irrigation construction increased greatly until the early-1980s, and the reason for this lies in the high economic returns on such investments. On the one hand, the cost of creating a unit of irrigated land has increased over the last four decades, as new construction progressed from relatively easy projects to more difficult ones. On the other hand, the irrigation infrastructure and the seed-fertilizer technology reinforced each other to increase the productivity of irrigated agriculture, thereby maintaining the profitability of new construction investments and counteracting increased construction costs. Taking these factors into account, the rates of return on new irrigation construction investments in the last four decades are estimated, based on 1986 constant prices.

We first identify the trend in the capital costs of creating a unit of irrigated land. Historical changes in the real capital costs of creating one hectare of irrigated land are

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[4] Around 1960, the share of O&M expenditures increased substantially. This was due to the expenditures required for major repairs in many systems following flood damage in 1959.

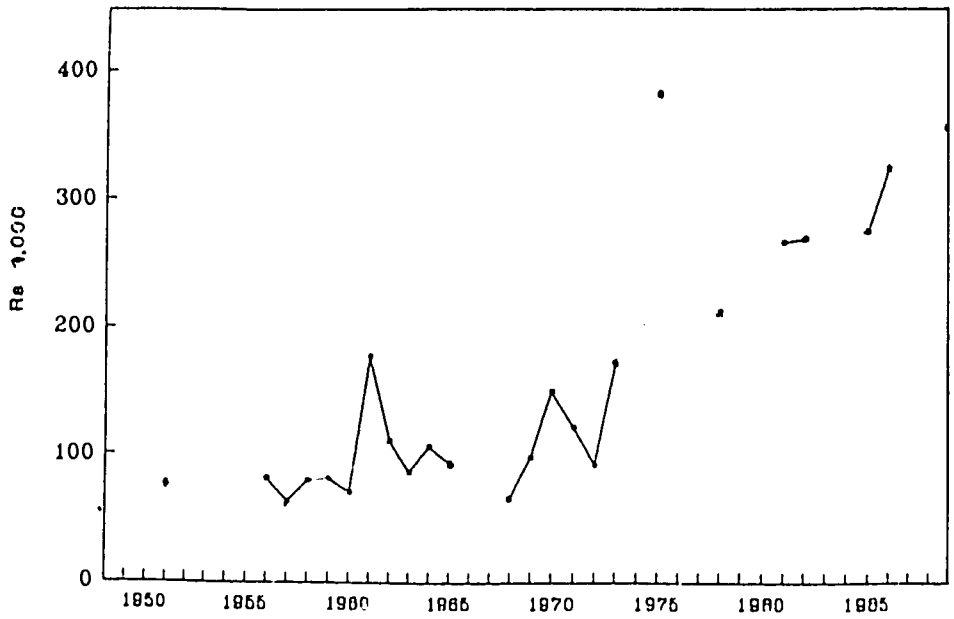
shown in Figure 1.2, based on 49 new irrigation construction projects for which detailed capital investment data are available. As defined earlier, the capital costs include only investments related to irrigation infrastructure. An increasing trend in the unit cost is apparent. The cost escalation has become more apparent since the early 1970s as irrigation construction projects shifted from small-scale "restoration" type to large-scale transbasin ones, such as the Mahaweli Project. This trend suggests that new irrigation construction in the post-independence period began in relatively easy projects and moved to more difficult ones. As a result, the construction cost per hectare in the late 1980s was more than five times that in the 1950s, in real terms.

The following result is obtained when the exponential time-trend curve is fitted to the data:

$$K^* = \underset{(3.411)}{1.637} + \underset{(6.763)}{0.047t}, \quad R^2 = 0.685,$$

where: K^* = capital cost per hectare including capital interest (in Rs 1000) in 1986 prices,
t = time (48 to 89),
R^2 = coefficient of determination, and
the figures in parentheses are t-ratios.

Figure 1.2. Changes in the real capital cost per hectare (including capital interest evaluated at 10% per annum) of new irrigation construction, 1951-89, in 1986 prices.



Source: Aluwihare and Kikuchi (1991)

For the benefit side, we assume rice is the crop to be grown in the newly created irrigation systems. In order to analyze the complementary relationship between irrigation and seed-fertilizer technology, three different seed-fertilizer technology levels are considered: 1) Traditional Varieties (TV) with 0 kg/ha of nitrogen application; 2) Old Improved Varieties (OIV) with 60 kg/ha of nitrogen; and 3) New Improved Varieties (NIV) with 120 kg/ha of nitrogen. The rice output for each variety group at each nitrogen level is estimated by using the national average fertilizer response function for each group (Kikuchi and Aluwihare 1990a).

Both the benefit-cost (B/C) ratio and the internal rate of return were estimated. The formula used to calculate the B/C ratios is as follows:

$$\frac{B}{C} = \frac{\sum_{k=0}^{l-1}(1+i)^k (l-k) [(R-c)/l] + \sum_{j=1}^{n}[(R-c)/(1+i)^j]}{(1+i)^m K}$$

where; R = annual increase in income due to the project, C = annual O&M cost to maintain the benefit stream, K = capital cost, n = lifetime during which the benefit stream continues to accrue, l = time in years from the commencement of the accruing of benefits to the completion of the project m = average gestation period of the capital investment, i = interest/discount rate (assumed to be 10 percent). The first term of the numerator in the right hand side of the formula, which is defined if and only if $l \geq 2$, is introduced to take into account the cases where part of the benefits starts accruing before the project completion, assuming linear increases in benefits from zero to the full benefit level. The internal rate of return is estimated as r that satisfies the following equation:

$$(1+r)^m K = \sum_{k=0}^{l-1} (1+r)^k (l-k) [(R-c)/l] + \sum_{j=1}^{n}[(R-c)/(1+r)^j]$$

The benefit flow is measured by an increase in agricultural income (gross value added). The increase is estimated by subtracting the current input cost (seed, fertilizer, chemicals, fuel, etc.) from the value of produce from the newly created irrigated land.[5] Rice output is valued by the average domestic market price for 1985-1987. The cropping intensity of the systems is assumed to be 1.3, which is the average for all the major irrigation systems for the entire study period (see Table 1.1).[6] The annual O&M

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[5] Increases in labour costs for crop production due to irrigation were not subtracted. This assumes that the additional labor is available at zero opportunity cost. As explained earlier, almost all new irrigation construction projects in Sri Lanka have been settlement schemes. Since the settlers in these irrigation systems were those who had difficulty in finding productive employment in their prior locations, their opportunity cost, if not zero, would have been quite low.

[6] More detailed analysis of the cropping intensity of the dry-zone major irrigation systems will be given later.

Table 1.6. Benefit-cost ratios and internal rates of return on investments in new irrigation construction, based on 1986 prices.[a]

	Based on estimated construction cost[b]			Based on actual construction cost[c]		
	Technology level[d]			Technology level[d]		
	Traditional Varieties N=0kg	Old Improved Varieties N=60kg	New Improved Varieties N=120kg	Traditional Varieties N=0kg	Old Improved Varieties N=60kg	New Improved Varieties N=120kg
1948-49	2.3 (20)			na		
1950-59	1.7 (15)			1.7 (15)		
1960-69	1.0 (10)	1.6 (15)		1.0 (10)	1.5 (14)	
1970-74	0.7 (7)	1.1 (11)	1.6 (15)	0.9 (9)	1.4 (14)	2.1 (20)
1975-79	0.5 (6)	0.9 (9)	1.3 (12)	0.5 (5)	0.8 (8)	1.1 (11)
1980-84	0.4 (4)	0.6 (7)	0.9 (10)	0.4 (3)	0.5 (5)	0.8 (8)
1985-89	0.3 (3)	0.5 (5)	0.7 (8)	0.3 (3)	0.5 (5)	0.7 (7)

[a] Internal rates of return are shown within parentheses. na = data are not available.

[b] The capital investment cost per hectare of new irrigation construction is estimated by the following equation: $K = 1.637 + 0.047t$; where K = capital investment per hectare with interest and t = time (48, 49,..., 89).

[c] The actual capital investment cost of new irrigation construction projects; weighted averages for the projects completed in the periods shown, using the command area as weights.

[d] Technology levels assumed for measuring the benefits from newly created irrigated land based on the following rice production functions under irrigated conditions:

Traditional Varieties $Y = 1500 + 10N - 0.09N^2$
Old Improved Varieties $Y = 1900 + 14N - 0.06N^2$
New Improved Varieties $Y = 2400 + 21N - 0.08N^2$

where Y = rice yield (kg/ha) and N = nitrogen input (kg/ha).

The benefits are measured by the increase in agricultural income (gross value added). The opportunity cost of labor is assumed to be zero. The total current input cost is estimated assuming the ratio between the total current input and the nitrogen cost to be 2.5.

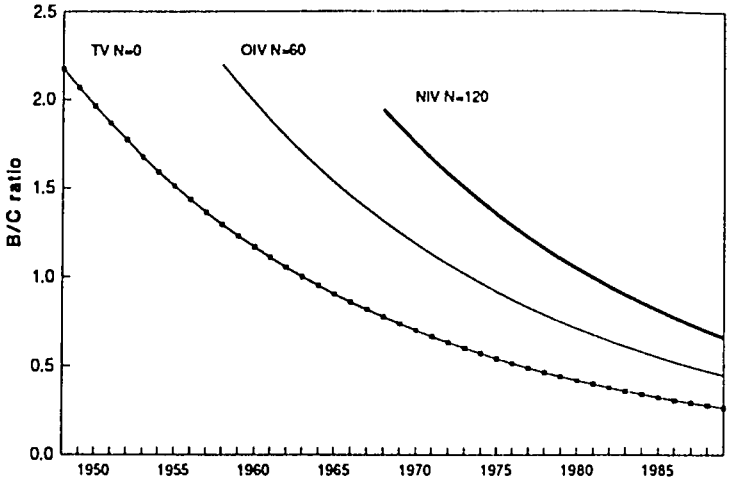
Source: Aluwihare and Kikuchi (1991)

cost of new areas brought under irrigation are assumed to be Rs 740/ha at 1986 prices.[7] It is assumed that with this level of O&M, irrigation systems can sustain their operation for 50 years.

The estimated rates of return are summarized in Table 1.6 by period, and the estimated B/C ratio series are shown in Figure 1.3 by level of seed-fertilizer.technology. Several points should be noted. First, irrigation construction was a lucrative investment

[7] This is the level that the Irrigation Department set as the "desired level" of O&M for the major irrigation systems (IIMI 1989).

Figure 1.3. Changes in the benefit-cost ratio of new irrigation construction investments, 1948-89, by level of seed-fertilizer technology, in 1986 prices.



Note: TV = Traditional Varieties
OIV = Old Improved Varieties
NIV = New Improved Varieties

Source: Aluwihare and Kikuchi (1991)

opportunity just after independence. The B/C ratios in the late 1940s were as high as 2.3 (Figure 1.3). For the 1950s, it was 1.7 on the average (table 1.5). Reflecting the increasing trend in the unit construction cost, however, the B/C ratio under the traditional rice technology (represented as "TV N=0") declined rapidly, and it went below 1.0 in the early 1960s. Had there been no progress in the technology from the traditional level, the economic potential of irrigation construction would have been exhausted within fifteen years after independence.

Second, the progress in seed-fertilizer technology compensated for the increases in construction costs to a large extent, and preserved the profitability of new construction investments. The introduction of improved rice varieties and the associated increase in fertilizer application resulted in successive upward shifts of B/C ratio curves from the previous technology levels; in terms of the horizontal axis, the degree of the upward shift was about 10 years for both Old Improved Varieties and New Improved Varieties.

Third, the rates of return on construction investments continued to decline even with the highest level of technology, cutting across the B/C ratio = 1.0 line by the early 1980s. This suggests that, given the present level of rice technology, the increasing real capital cost for construction, and the price structure in the mid-1980s, the irrigation sector in the country has come to a stage at which the investments in new irrigation construction cannot be economically justified.

The analysis above gives clear evidence for the following statements:

1) The massive investments in irrigation new construction after independence were induced by the high economic potentials of such investments; the profitability was high at the initial stage and was then preserved by dynamic interactions between irrigation infrastructure and seed-fertilizer technology.
2) The economic potential for new irrigation construction had been exhausted by the mid-1980s.

Short-Term Fluctuations

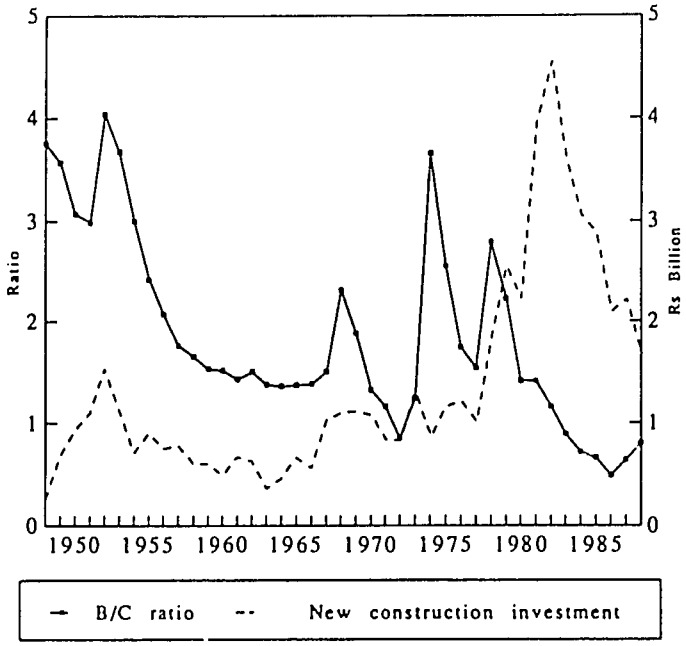
The new irrigation construction investments have experienced large short-run to medium-run fluctuations in the past. If new irrigation construction was always a lucrative investment opportunity, as the long-term analysis above indicates, why did the government not make a continuous effort to invest in it? The answer can be sought in two areas: fluctuations in rice prices, and the availability of investible funds.

The rates of return on construction investments depend critically on the price of rice. For a government making decisions on irrigation investments, the import price of rice is of particular importance. An overriding factor in the food policy of the Government of Sri Lanka has been the need to supply a sufficient amount of rice to the consumers, through the food ration/food stamp system or at relatively low and stable prices in the open market. It is therefore reasonable to suppose that the government, as an importer of rice, strengthened its efforts to increase domestic rice production in response to rising world rice prices. It can therefore be hypothesized that, besides pursuing the long-term objective of attaining self-sufficiency in rice, government decisions on irrigation investments have been strongly influenced by short-term fluctuations in world rice prices and their effects upon the social payoff from irrigation investments as well as the country's foreign exchange reserve.

As a test of this hypothesis, the benefit-cost ratios of investment in new construction were re-estimated by evaluating the costs and benefits at current prices. On the benefit side, the rice output was evaluated by the current Colombo c.i.f. price of rice. Changes in seed-fertilizer technology were incorporated by aggregating the income generated under each technology level into a single series, using the percentage shares of area planted with each type of rice variety in each year. On the capital cost side, the unit cost at current prices of constructing one hectare of new irrigated land was obtained by applying the GDP implicit deflator to the real unit cost estimated from the trend line presented earlier.

The series of B/C ratios thus estimated are shown in Figure 1.4, together with the series of annual investments in new construction. Close associations between changes in the B/C ratio and construction investments are discernible. While the government response to the changes in the payoff was rather quick until the 1960s, the process began to involve substantial time lags after around 1970. This could be explained by the fact that, whereas in earlier years there were many sites where construction projects could be initiated easily, project preparation and implementation have become more difficult and time-consuming in recent years.

Figure 1.4. Changes in the benefit-cost ratio of new construction (evaluated at current import price of rice) in comparison with changes in the new construction investments, 1948-88, in 1986 prices.

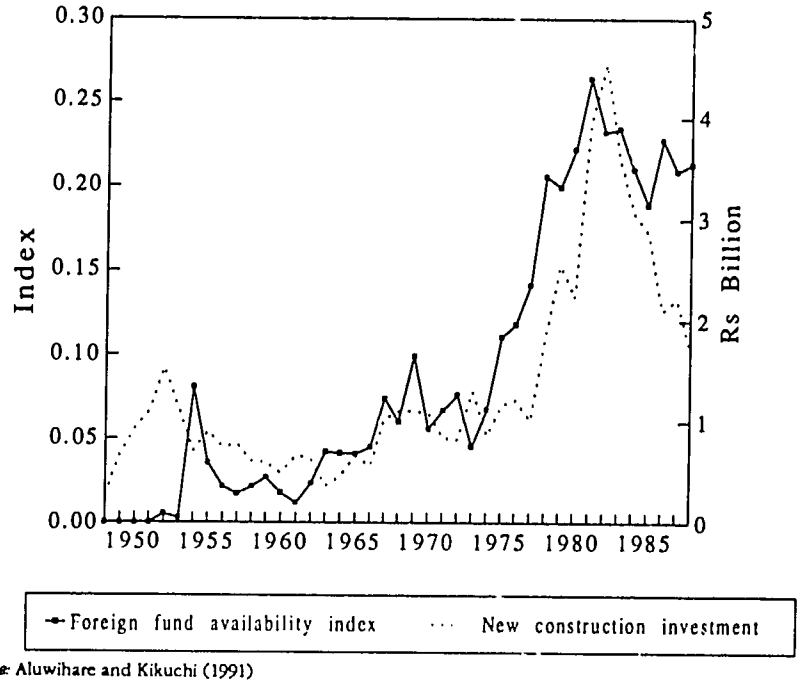


Source: Aluwihare and Kikuchi (1991)

A high rice import price clearly has a direct impact on government decisions in irrigation construction, through raising the payoff of the investments relative to other public investment opportunities. This implies the reallocation of government funds from other public investment opportunities and/or from recurrent expenditures such as those for importing rice for the food ration program. Since the government's investible funds have always been scarce, their availability would have constrained this reallocation process to a great extent. To identify how the availability of funds affects investment in irrigation construction, we prepared a foreign fund availability index which is defined as the ratio of the total foreign official assistance, consisting of the foreign loans and grants, to the total government budget. Historical changes in this index are shown in Figure 1.5, together with the trend of new irrigation construction investments.

A close association is apparent between this index and new construction investments. In particular, the association is quite strong after the early 1960s. The investment spurt in the late 1960s coincided with an increase in the index during the same period. The unprecedented high investment spurt that began in the late 1970s was narrowly preceded by a rapid increase in the availability of foreign funds, and the investments began to decline after the index hit a peak in 1981. All this indicates that

Figure 1.5. Changes in the foreign fund availability index in comparison with changes in the new irrigation construction investments, 1948-88, in 1986 prices.



Source: Aluwihare and Kikuchi (1991)

the government decision to invest in irrigation construction was seriously constrained by the availability of funds, particularly those of foreign origin. It could be said that the last two peaks in construction investment, particularly the third one, were largely created by donor countries and international lending agencies; they too reacted to the high profitability of investments in irrigation construction.

Our analysis thus indicates that rates of return and foreign fund availability are major determinants of government investment in new irrigation construction.[8] It is worth emphasizing that the government also responded to changes in the social profitability

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[8] The following estimate of the investment function gives statistical support for the determinants of new construction investments:

$$\underset{}{\ln I_t} = \underset{(4.01)}{1.265} + \underset{(2.26)}{0.221 \ln (B/C)_t} + \underset{(3.77)}{1.541\ AID} + \underset{(4.67)}{0.527 \ln I_{t-1}}$$

R^2 (adj.) = 0.819, D.W. stat. = 2.001,

where; I_t = irrigation construction investments in year t; $(B/C)_t$ = B/C ratio in year t evaluated at current prices; AID = foreign fund availability index; and figures in parentheses are t-ratios. It should be noted that a very similar relationship between irrigation construction investments and world rice prices/foreign fund availability is observed in the Philippines (see Hayami and Kikuchi 1978 and Svendsen and Ramirez 1990).

of the investment. It is often said that irrigation-settlement projects in Sri Lanka have always been a hot social issue in which political and social factors exercise undue influence (e.g., Mendis 1989; Nijman forthcoming). Nevertheless, the allocation of government funds for irrigation construction has been guided by economic considerations, i.e., by the economic returns on the investment, while being constrained by the scarcity of investible funds and foreign exchange reserves.

FUTURE PROSPECTS FOR NEW IRRIGATION CONSTRUCTION

Figure 1.4 reveals that the B/C ratio of the investments in irrigation construction went down sharply from the late 1970s and hit an unprecedented low in 1986. Such a drastic decline was due partly to the increased construction costs and partly to the historic low price in the world rice market. Although the B/C ratio shows an upward trend after 1986 as the world rice price rebounded, its level in 1988 was still below 1.0. Irrigation construction investment at present represents the classical case of diminishing returns. It could be said that the era of "major" irrigation construction in Sri Lanka has ended, unless major breakthroughs in technology are forthcoming either in construction or in agriculture, or in both.

This statement raises two questions. First, what would the level of the rates of return for irrigation construction be if the world rice price rose in the near future to the level experienced during the food crisis period in the 1970s? To check this, the rates of return are estimated for three years in the last decade of this century assuming the average rice import price experienced during the period from 1974 to 1979, which is more than 300 percent higher than in 1986 in terms of the price of rice relative to construction cost. The results show that the high rice price raises the B/C ratio to slightly more than 1.0 with the present level of construction costs (Table 1.7). However, even with such a high rice price, it will go down quickly to a level below 1.0 by the end of this decade.[9]

Second, since the mid-1980s when Sri Lanka attained near self-sufficiency in rice, efforts have been made to diversify the cropping pattern on rice-based irrigation systems. Could the benefits from irrigation construction be drastically increased by switching the crops to be grown in the systems from rice to high value nonrice crops? To check this, re-estimations of the rates of return were attempted, assuming that the entire planted area in the yala season with a cropping intensity of 0.3 is planted with high value nonrice crops, such as chili, onion, and gherkin. Based on our recent study (IIMI 1990a), the gross value added of these high value crops is assumed to be at a level 740 percent higher than that of rice if the rice c.i.f. price is at the 1986 level. For valuing rice output, the World Bank predictions are used after linking with the

[9] It is worth noting that the World Bank predicts a declining trend in the world rice price after 1989. Its latest prediction at January 1990 is as follows: 1989=100.0, 1990=84.5, 1995=72.1, and 2000=71.2. The predicted level for the year 2000 is not only less than the level assumed here but less than the 1986 level.

Table 1.7. Rates of return on the irrigation construction investment for different assumptions on the world market price of rice and crops grown.[a]

	Rates of return[b]					
	1990		1995		2000	
High world market price: Import price of rice (Colombo c.i.f.) relative to the construction cost index; average for 1974-79[c]	1.43	(13)	1.13	(11)	0.89	(9)
Crop diversification: Complete diversification in the yala season with high performance nonrice crops[d]	1.47	(14)	1.11	(11)	0.88	(9)

[a] For all cases, the technology level of "New Improved Varieties; N=120kg" for rice is assumed. The capital cost of construction is estimated on the basis of the trend curve.

[b] The benefit-cost ratio. The internal rates of return are shown within parentheses.

[c] The average relative price of rice for 1974-79 is assumed. The same assumption is adopted in estimating the benefit, except that the nitrogen price is evaluated by using the price with the subsidy added, instead of the farm-gate price.

[d] It is assumed that the entire cultivated area in the yala (dry) season with a cropping intensity of 0.5 can be planted with the high performance nonrice crops. The gross value added of the nonrice crops is assumed to be Rs 72,000/ha, in 1989 prices.

Source: Aluwihare and Kikuchi (1991)

Colombo c.i.f. price. The results shown in Table 1.7 indicate that, with the unit capital cost in 1990, the B/C ratio will be raised to 1.2, but it soon declines to below 1.0.[10]

Our conclusion that the era of "major" irrigation construction has ended is thus maintained under these two extremely favorable cases for new construction, cases

[10] It should be noted that in reality there are many difficulties and constraints in promoting crop diversification in rice-based irrigation systems on a wide-scale (IIMI 1990a; 168-178): it is difficult to identify economically viable nonrice crops which can replace rice; some high value nonrice crops are available for farmers to adopt, but usually these crops require higher input intensity as well as more deliberate water management than rice does; not all soil types found in the irrigation systems are fit for growing nonrice crops; the markets, both for outputs and for inputs, are not well-developed; etc. There is no doubt that needs as well as potentials exist for crop diversification, but there are many prerequisites to attaining it, including the capability to manage water better than is necessary for rice.

which are hardly likely to occur.[11] The conclusion is further reinforced when compared to other types of irrigation investments which have emerged in the management phase.

MANAGEMENT PHASE: REHABILITATION AND WATER MANAGEMENT IMPROVEMENT PROJECTS

A new trend in irrigation investments emerged in the mid-1970s; investment in irrigation system rehabilitation appeared and has rapidly increased its share in the total irrigation investments. Following this, with a short time-lag, has been a spate of water management improvement projects. Why? It is natural to hypothesize that the diminishing returns on new irrigation construction, due to massive investments in the past, have increased the relative profitability of the investments in improving and enhancing the quality of existing systems.

Let us examine this hypothesis by estimating the rates of return on selected rehabilitation and water management projects. Two completed major rehabilitation projects — the Tank Irrigation Modernization Project (TIMP) and the Gal Oya Water Management Project (Gal Oya) — and three water management improvement projects, implemented in the Kimbulwana, Pimburettawa, and Nagadeepa systems, are selected for post-project cost-benefit analysis.

The same cost-benefit analysis framework as for the constant price estimation for new construction investments is applied; both the capital costs and benefits are valued at 1986 prices, and the benefits are measured by the increases in agricultural income due to the projects. There could be various possible sources of benefits from rehabilitation/water management projects. In this study, we take into account only two sources of possible benefits: changes in the cropping intensity, and reduction in yield gaps between the head- and tail-end sections due to better water distribution after the project. Rice is assumed to be the crop grown, with yields identified by system, except TIMP for which the technology level "NIV; N=120" is assumed. The gross value added ratio of rice production is assumed to be 80 percent. O&M cost is assumed to be Rs 740 per ha. The lifetime of project benefits is assumed to be 20 years for major rehabilitation projects and 15 years for the water management projects.

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[11] Note the magnitudes of changes assumed in our sensitivity analyses. Unlike appraisal reports for this kind of irrigation project in which sensitivity analyses are made assuming 10-20% changes in crucial parameters in cost-benefit analyses, ours are in the order of several hundred percent. Any possible changes in the parameters other than those treated here will be within these magnitudes. For instance, a basic assumption in the cost-benefit analysis made thus far for irrigation construction is that the newly created systems are operated at a cropping intensity of 1.3. What if it is 2.0? The benefits then will be increased by about 50% over the 1.3 case. Such an increase in benefits is well within the magnitudes.

The results of the estimations are summarized in Table 1.8, together with the rates of return of new construction investments in the 1980s for comparison. As expected, the two major rehabilitation projects both show rates of return higher than new construction. In particular, the Gal Oya Project reveals high rates of return for rehabilitation investments. It is interesting to notice that the level of profitability of this project is almost at the same level that investments in irrigation construction enjoyed forty years ago, when the irrigation sector started its construction phase after independence. The Gal Oya case thus gives clear support to the hypothesis that rehabilitation is a more lucrative investment opportunity than new construction at the present stage of irrigation development.

However, not all major rehabilitation projects are necessarily as successful as the Gal Oya project, as illustrated by the TIMP case. The difference in the rates of return between TIMP and new construction is marginal. It has been pointed out that TIMP, as the first major rehabilitation project in the country, encountered many difficulties in implementation; particularly serious was its strong bias towards engineering and capital intensive directions while giving little attention to the farmer-beneficiaries in the design and O&M processes (e.g., Murray-Rust and Rao 1987). It is said that the most valuable contribution made by TIMP is that it has given many useful lessons to the rehabilitation projects that followed it. It is noteworthy that the Gal Oya project, which is said to have absorbed many useful lessons offered by TIMP (Merrey and Murray-Rust 1987), showed far better economic performance than its predecessor. Improving water management through introducing institutional changes, including farmers organizations, became a central feature of the Gal Oya project; it thus included elements of both rehabilitation and water management improvement projects.

Table 1.8. Rates of return on irrigation investments in the 1980s: Comparison of B/C ratios and internal rates of return of new construction, major rehabilitation, and water management improvement projects, based on 1986 price estimates.

	B/C ratio	Internal rate of return (%)
I. New construction Projects:		
The average for the 1980s[a]	0.8	9
II. Major Rehabilitation Projects:		
TIMP[b]	1.1	11
Gal Oya	2.3	24
III. Water Management Projects:		
Kimbulwana	13.4	83
Pimburettawa	7.4	77
Nagadeepa	0.4	6

[a] For the technology level "New Improved Varieties; N=120kg" and the estimated construction costs (From Table 1.6).

[b] The rates of return for the Tank Irrigation Modernization Project are based on "would-be" benefits assumed in the project appraisal report. For all other rehabilitation and water management projects, the project benefits are based on the data that show changes before and after the projects.

Source: Aluwihare and Kikuchi (1991)

More striking results in Table 1.8 are the very high economic performanc that some water management improvement projects reveal. The Kimbulwana and Pimburettawa Projects yielded internal rates of return as high as 70 to 80 percent, implying that such projects have been terribly underinvested. It is not surprising at all, however, to see such results for water management projects, if one examines the present level at which many major irrigation systems in Sri Lanka are being operated and maintained: inequitable water distribution, considerable wastage of water by head-end farmers, poor management of water in the maha season leading to water shortage in the yala season, poor maintenance of physical structures, etc. Rectifying these defects results in substantial increases in system performance, while requiring little financial investment.

However, not all water management projects are successful. Among the three projects studied, we failed to detect any systematic improvement in system performance after the intervention in Nagadeepa. There are two important differences between this and the other two projects. One lies in the inadequate follow-up to consolidate the water management improvements by the managing agency at Nagadeepa. The other lies in the components related to physical structure improvements, the rehabilitation and/or modernization components, however minor they were, accompanied the institution-building and water management improvement components in Kimbulwana and Pimburettawa, whereas they were almost nonexistent in Nagadeepa.

An important lesson that could be derived from these experiences is the importance of physical structure improvements as a precondition to achieving better water management through farmers' participation and cooperation. The two success cases suggest that very modest investments in rehabilitation are sufficient to provide the basis for water management improvement.[12] A second lesson is the importance of sustained effort to achieve the full potential of improvements over the long term.

The available evidence thus indicates that, given proper design and implementation, the economic performance of rehabilitation and water management improvement projects is far better than that of new construction. The rapid increase in rehabilitation

[12] The capital cost per hectare of these water management projects, in 1986 prices, can be roughly broken down as follows (Kikuchi and Aluwihare 1990b):

	Kimbulwana	Pimburettawa	Nagadeepa
	Rs/ha		
Rehabilitation of physical structures	4,332	4,734	596
Institution building	0	902	621

Note that the amount spent for physical improvements in Nagadeepa was less than the assumed level of O&M cost per hectare, and that the rehabilitation component was quite similar for Kimbulwana and Pimburettawa, i.e., US$ 160/ha (using the average exchange rate of US$ 1.00 = Rs 28.00 in 1986).

investments and the proliferation of water management improvement projects in and after the late 1970s must have been induced by such changes in the relative profitability of these investments.

One may think that, even if their rates of return are higher, the absolute amount of benefits to be generated from such projects would be far less than the benefits obtained from new construction projects. If that were the case, considering the overhead and other transaction costs involved in project preparation and implementation (which are not taken into account in our cost-benefit analysis), it might not be worth pursuing the opportunities for rehabilitation and water management improvement. To answer this question, the project net present value, defined as the present value of the total project benefits less the present value of the total project capital

Table 1.9. Comparison of the Net Present Values of new construction and rehabilitation/ water management improvement projects of selected irrigation systems in Sri Lanka, in 1986 prices.

	New construction (1)	Rehabilitation/ water management (2)	(2)/(1)
Gal Oya			
Construction period[a]	1949-61	1980-87	
Command area (ha)	38,000	25,000[d]	
Total capital cost[b] (Rs million)	2,190	450	0.21
Internal rate of return (%)	12	24	2.00
Net Present Value[c] (Rs million)	1,459	1,055	0.72
	(960)[d]		(1.10)
Kimbulwana			
Construction period[a]	1953-62	1979-80	
Command area (ha)	560	666[e]	
Total capital cost[b] (Rs million)	21.8	2.9	0.13
Internal rate of return (%)	16	83	5.19
Net Present Value[c] (Rs million)	53.3	41.3	0.77
Pimburettawa			
Construction period[a]	1969-75	1986-89	
Command area (ha)	1,619	2,153[e]	
Total capital cost[b] (Rs million)	89.0	12.1	0.14
Internal rate of return (%)	25	77	3.08
Net Present Value[c] (Rs million)	168.2	81.3	0.48

[a] For the new construction projects, the end-year is defined as the year by which time 90 percent of the total capital investment was made.

[b] Capital interest during the gestation period is not included.

[c] Net Present Value of project = total capitalized benefits (net of O&M costs) minus total capital investment costs. Costs and benefits are compounded/discounted by an interest rate of 10 percent.

[d] For the Left Bank only.

[e] The command area after the project.

Source: Aluwihare and Kikuchi (1991)

investments, are estimated and compared between new construction and rehabilitation/water management improvement for three systems (Table 1.9).

In the case of the Gal Oya system, the net present value of the new construction project in 1986 prices was Rs 1,459 million while that of the rehabilitation project was Rs 1,055 million. If the benefits of the new construction project are prorated, according to its command area share, to the Left Bank to which the rehabilitation project was confined, the net present value of the rehabilitation project was even larger than that of the new construction project. Similar results are obtained for the water management projects. We conclude that investments in rehabilitation and water management improvement are valuable economic opportunities in terms not only of the rates of return but also of the absolute size of the benefits to society.

IMPLICATIONS FOR POLICY AND RESEARCH IN IRRIGATION MANAGEMENT

Policy Implications

Future direction of the irrigation sector. The most important general implication of our study is that development of the irrigation sector in Sri Lanka has shifted from the construction of new irrigation systems to rehabilitation/modernization, coupled with an improvement in water management, of the existing systems. It is clear that, given the present state of irrigation development in the country and the present levels of technology in agriculture and construction engineering, little economic potential is left to be exploited by new irrigation construction. This is not to deny that there could still be some potential for developing new irrigation systems in some parts of the country, most likely small- to medium-sized. Generally speaking, however, the era of major irrigation construction in Sri Lanka is at an end.

Instead, now that the irrigated land base has been well-established, attention in the irrigation sector should be directed towards, and concentrated on, rehabilitation and modernization, and improvement in water management, including crop diversification, of the existing systems. The potential for increasing agricultural income through these means is high. In particular, water management improvement is unduly under-invested, leaving huge potentials to be exploited from now on. It is the uncontested, inexorable direction for the irrigation sector in Sri Lanka to go into the "management" stage, while getting out of the ingrained "construction bias" that has become built in over the last four decades.

The experience in the irrigation sector in Sri Lanka could be typical of many other countries in the Asian tropics where land is scarce. Being a small island country, the change in emphasis in the development of the sector has been as clear as if observations had been made in a laboratory. In larger countries, consisting of many regions with diverse development stages, it may be more difficult to identify such a change at the national aggregate level. However, having had a construction stage

during the last few decades, in common with Sri Lanka, the irrigation sector in many of these countries should have reached a similar stage by the 1980s. Sri Lanka's experience illustrates that the management orientation is inevitable in the irrigation sector in Asia, and that the economic potentials in this direction are large.

Macro-economic context. Agricultural development is a necessity for the country's economic development. The major efforts of the government since independence have been directed towards the agricultural sector in general and the irrigation sector in particular. This direction has been correct: countries that have underfunded agriculture have paid a high price in terms of foregone development, and Sri Lanka seems to have avoided this trap. The development of the irrigation sector has been critical for the agricultural development in this country, and it continues to be so, though with a different emphasis. Keeping and upgrading the performance of the existing irrigation systems in the most efficient manner would be consistent with the overall national development policy, leading towards a higher level of economic performance of the entire economy.

With a well-established base for food production, not only the irrigation sector but also the economy as a whole needs to be diversified. As stated in any text book on development economics, an important role of agriculture in economic development is to supply resources, financial as well as human, to the rest of the economy. So far, in Sri Lanka, this role has been played by the tree plantation sector. As Table 1.10 indicates, the order of resources that the rice sector has been absorbing from the rest of the economy, the major part of which has been for irrigation development, is roughly comparable to the "agricultural surpluses" that the tree sector has been generating. The shift from the construction to the management stage in the irrigation sector will release the bulk of these resources to other sectors of the economy, in addition to foreign exchange savings/earnings that will be forthcoming if the sector is successful in crop diversification with import-substituting, and/or exportable, nonrice crops.[13]

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[13] The following rule of thumb calculation gives indicative orders of the resources to be released from the irrigation sector by the shift from the construction to the management phase. Assume: 1) the irrigated land area of the country remains at the present level of about 500,000 ha (major and minor irrigation); 2) this existing irrigated land-base requires rehabilitation or modernization every 20 years so that 25,000 ha need rehabilitation each year; 3) capital costs for rehabilitation/modernization are at the level needed for the Gal Oya rehabilitation project (about Rs 25,000/ha in 1986 prices; note that the "rehabilitation" needs for the water management projects in Kimbulwana and Pimburettawa were one-fifth of this level); and 4) O&M needs are Rs 740/ha at 1986 prices for the entire irrigated area (note that the actual government O&M expenditures are about Rs 300/ha for the major irrigation systems and that no expenditure was incurred by the government for the minor irrigation systems of about 180,000 ha). The annual investment needs are then estimated to be around Rs 995 million, which is less than 30 percent of the average annual total irrigation investments for the period from 1978 to 1988. At least 70 percent of the funds which have been invested in irrigation development could be released for other development purposes. If O&M costs were borne by the farmers, instead of using scarce government resources, this release rate would increase to more than 80 percent.

Table 1.10. Total net tax and levies from the tree plantation sector and total subsidies to the rice sector including irrigation investments, 1960-1982, in current prices.

	Total net tax and levies from tea, rubber and coconut (1)	Total producer and consumer subsidies to the rice sector[a] (2)	(2)/(1)
	----------Rs million ---------		
1960	386	322	0.83
1965	493	407	0.83
1970	499	652	1.31
1975	806	824	1.02
1980	4,428	1,179 [b]	0.27
1982	3,357	3,498 [b]	1.04

[a] Includes the public expenditures on irrigation
[b] Only the public expenditures on irrigation.

Source: Thorbeck and Svejnar (1987), and Aluwihare and Kikuchi (1990).

Government and donor responses to the change in emphasis. During the four decades since independence, the government, together with international donor agencies, has been responding fairly reasonably to the economic opportunities that have been provided by the irrigation sector through the development of the irrigation infrastructure. It is reasonable to expect that the government will respond to the new opportunities. In fact, though there has been a certain time lag, many steps have been taken in the new direction since the early 1980s, some of which are well-documented in the literature (e.g., IIMI 1986 and 1990b).

Notably, government efforts in the irrigation sector towards management orientation have borne fruit in the form of the Irrigation Management Policy Support Activity (IMPSA), launched in April 1990 with an 18-month project period. IMPSA, which is financed by USAID and assisted by the Irrigation Support Project for Asia and the Near East and IIMI, aims:

> to develop specific policy statements and suggest implementation strategies to expand on and fill the gaps in the broad policy framework on "participatory management in irrigation schemes" as outlined in the Cabinet Paper on this subject approved in late 1988. ..... IMPSA provides an opportunity for a fresh synthesis of experience and the refinement of policy to ensure the continued and timely transition to a new participatory management system (IMPSA 1990; 1).

In short, IMPSA is a policy formulation process in transition from the construction phase to the management phase, which represents a conscious government response to the changing momentum in the sector.

Guidelines for irrigation construction/rehabilitation projects. The cost-benefit analyses in this study were based on the performance of irrigation projects implemented in the past. This process of reviewing the investment performance revealed certain ranges for crucial parameters in determining performance. Referring to these ranges, a rough estimate can be made for the "reasonable" level of unit capital cost in order for new irrigation construction/rehabilitation projects to be economically viable.

Crucial parameters in determining investment performance are: 1) rice price, 2) rice yield, 3) cropping intensity, 4) the extent of crop diversification with nonrice crops which generate higher income than rice, and 5) the gestation period of a project (construction period in the case of new construction). It can be said, at least in the Sri Lankan context, that all other factors, such as agricultural input prices and project life span, are of minor importance in the benefit determination under normal circumstances. As illustrations, unit capital costs that make the B/C ratio equal to 2.0 under certain levels of performance in terms of the crucial parameters are presented in Tables 1.11 and 1.12 for new irrigation construction and major rehabilitation projects, respectively. The level of B/C ratio = 2.0 is chosen as the minimum level of rate of return for this kind of investment.[14]

It is indicated that unit capital cost should be, at the highest, about US$5,000 for new construction projects and US$2,500 for major rehabilitation projects, if these projects are to be economically viable. We have to remember that the majority of the past projects, while envisaging some performance level in the second category in these tables ("reasonable expectation"), ended up in the first category ("reality"). It requires considerable management and institutional efforts, after the project as well as during project implementation, to attain the target levels for the crucial parameters in this second category.

It should be noted that, although classified under "reasonable expectation," it is actually quite difficult to meet all the assumed levels for option II-5. For any project proposal with a capital cost of more than US$3,000 for new construction and US$1,500 for major rehabilitation, the assumptions need checking; there may well be unrealistic assumptions for some crucial parameters. Appraisal reports of capital intensive projects would make third category ("highly heroic") type assumptions as a last resort in order to raise the internal rate of return above a certain break-even level. Such a high level of performance has never been attained in Sri Lanka, though it may

[14] The Gal Oya rehabilitation project had a B/C ratio about this level and the level is much higher for some water management improvement projects. Any new projects should have a rate of return at this level or higher to be economically viable. At the order of cost and benefit in our examples with a discount rate of 10 percent per year, the B/C ratio of 2.0 roughly corresponds to an internal rate of return of 20 percent.

Table 1.11. Capital investments costs per hectare that make B/C ratio = 2.0 in 1990 prices: new irrigation construction.[1]

	Assumed parameters			Unit capital cost[2] Rs 1,000/ha(US$/ha)	
	Yield[3] mt/ha	Cropping intensity[4]	Crop diversification[5]	m=4	m=6
I. Reality[6]					
1.	4.0	1.3	0%	73 (1,900)	605 (1,500)
II. "Reasonable" expectation[7]					
2.	4.0	1.5	0%	85 (2,100)	70 (1,800)
3.	5.0	1.5	0%	106 (2,700)	87 (2,200)
4	6.0	1.5	0%	127 (3,200)	195 (2,700)
5.	4.0	1.5	30%	113 (2,800)	93 (2,300)
6.	5.0	1.5	30%	132 (3,300)	109 (2,700)
7.	6.0	1.5	30%	151 (3,800)	125 (3,100)
III. "Highly heroic" assumptions[8]					
8.	6.0	1.8	30%	191 (4,800)	158 (3,900)

[1] Basic assumptions: a) the entire command area to be created in new, not including any old cultivated areas; b) no opportunity cost for labor is used in the new system; c) the rice output is valued at Rs 5.20/kg (in paddy) which is the Colombo c.i.f. price linked with the World Bank projected rice price for the year 2000; and d) a gross value added ratio of rice production of 80 percent.

[2] Capital costs per hectare of the new command area which make B/C ratio = 2.0. Two different average gestation periods (m) of the project investments are assumed; four years and six years. The exchange rate assumed is US$1.0 = Rs40.00.

[3] Rice yield per ha to be realized after the project.

[4] The cropping intensity to be realized after the project.

[5] The percentage of the yala season crop area planted to high-value nonrice crops, the gross value added of which is assumed to be Rs 72,000/ha in 1990 prices.

[6] Assumes the average performance level attained by the irrigation new construction projects in the past.

[7] Assumes performance levels that could be attained with reasonable efforts in management aspects to ensure better O&M after the project than in the past.

[8] The performance levels which irrigation engineers-designers may wish to have in their desk work, but which have never been achieved in reality under the Sri Lankan setting.

Table 1.12. Capital investments costs per hectare that make B/C ratio = 2.0 in 1990 prices: major irrigation rehabilitation.[1]

	Assumed parameters			Unit capital cost[2] Rs 1,000/ha(US$/ha)	
	Yield[3] mt/ha	Cropping intensity[4]	Crop diversification[5]	m=3	m=5
I. Reality					
1.	4.0	+0.3	0%	25 (600)	21 (500)
II. "Reasonable"expectation[6]					
2.	4.0	+0.5	0%	36 (900)	29 (700)
3.	5.0	+0.5	0%	44 (1,100)	37 (900)
4.	6.0	+0.5	0%	53 (1,300)	44 (1,100)
5.	4.0	+0.5	30%	62 (1,600)	51 (1,300)
6.	5.0	+0.5	30%	69 (1,700)	57 (1,400)
7.	6.0	+0.5	30%	76 (1,900)	62 (1,600)
III. "Highly heroic" assumptions[7]					
8.	6.0	+0.7	30%	101 (2,500)	83 (2,100)

[1] Basic assumptions: a) two sources of benefits from rehabilitation, i) increase in the cropping intensity (including an increase in the command area after the project), and ii) 10 percent increase in the system's average rice yield due to the yield-gap reduction between the head- and tail-end sections resulted from better water management; b) no opportunity cost for labor is additionally required for agricultural production; c) the rice output is valued at Rs.5.20/kg which is the Colombo c.i.f. price linked with the World Bank projected rice price for the year 2000; and d) the gross value added ratio of rice production of 80 percent for newly added planted area (for the yield increase due to yield gap reduction, no additional current inputs are assumed to be necessary)

[2] Capital costs per hectare of the benefited area which make B/C ratio = 2.0. Two different average gestation periods (m) of the project investments, three years and five years, are assumed.

[3] Rice yield per ha to be realized after the project (assumed to be the same as the yield attained in the head-end section before the project).

[4] The increase in the cropping intensity due to the project. Assumes that the intensity before the project is 1.3 (the average for the major irrigation schemes at present).

[5] The percentage of the yala season crop area planted to high-value nonrice crops, the gross value added of which is assumed to be Rs.72,000/ha in 1990 prices.

[6] Assumes performance levels that could be attained with reasonable efforts in management aspects to ensure better O&M after the project than in the past.

[7] The performance levels which irrigation engineers-designers may wish to have in their desk work, but which have never been achieved in reality under the Sri Lankan setting.

become feasible if irrigation management research can successfully identify how to attain such a high performance.[15]

Research Implications

The irrigation sector has reached the management stage. However, there are many unknowns in pursuing this new direction. The economic potentials of new opportunities are large and realizable, as exemplified by the "success" cases of major rehabilitation and smaller water management improvement projects studied in our research, but necessary and sufficient conditions for realizing the potentials are not fully known. In the case of Kimbulwana, a successful water management improvement project, the Technical Assistant (TA) attached to the system played a key role in the project; without him there might have been no success. The question then arises as to why those in other systems failed. Even for this project, certain criticisms exist (Weeramunda 1985). Athukorala and Athukorala (1990) raise the same sustainability question for the Pimburettawa case. What are the decisive factors that made certain projects successful and certain others failures? How can a successful water management project be sustained? We have hypotheses but no systematic answers to these fundamental questions, and the replicability of these success cases is not assured without the answers. More research is definitely needed in this field, the profitability of which is firmly ensured by the huge economic potentials of the object itself.

Complementarity between physical and institutional improvements. Our study on rehabilitation/water management improvement projects found particular complementarity between the physical infrastructure and institutional improvements; for all the success cases, these two went hand in hand. It is clear that physical improvement alone cannot solve the problem of irrigation management and that institutional/organizational aspects are critical. The kinds of physical improvements that complement institutional improvements, and the conditions under which these two components best interact for cumulative improvements in system performance, are important areas of water management research suggested by this study.

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[15] The levels of unit capital cost referred to here should not be taken to mean that one can spend up to those levels in construction or rehabilitation projects. Every effort must be made to attain the best investment performance under the specific conditions and realities that each project faces. For instance, in the case of rehabilitation, a unit capital cost of US$1,500 at 1990 prices is referred to as a "reasonable" level. This does not mean that every rehabilitation project should aim at this level of unit capital cost. Given a certain level of performance, the unit cost of a project should always be minimized. In the case of the Irrigation System Management Project (an on-going major rehabilitation project which pursues cost-effective methods of system rehabilitation and modernization under "Essential Structural Improvement" "Pragmatic Rehabilitation" with a heavy emphasis on farmer organizations), the level of unit capital cost envisaged is 60-70 percent of the Gal Oya rehabilitation project, or about US$400-US$500/ha at 1990 prices. As we suggest, an important area of irrigation management research is to find the best balance/interactions between physical and institutional improvements in pursuit of better performance with the lowest cost combination.

Where does the potential lie? In conducting cost-benefit analyses for rehabilitation and water management projects, there are difficulties in identifying the benefits, since the sources of these benefits are numerous and often elusive. In addition to the two direct benefits (an increase in the cropping intensity and reduction in the yield gap between the head end and tail end due to better water management), which are taken into account in our cost-benefit analyses, there could be indirect ones. For example, well-rehabilitated and better-managed systems may lower O&M costs. Well-organized water users' groups, which are usually the central component of water management improvement projects, would be instrumental in making maintenance more effective, reducing damages to the physical structures, improving water distribution, reducing wastage of water, and achieving a higher cropping intensity and better crisis management in times of drought, etc. To the extent that they are identifiable, these indirect benefits should be included in our analysis, and research efforts should be made to identify the impacts of water management improvement upon these sources of benefit.

However, our data clearly show that the two direct sources of benefits are by far the major ones. It is particularly the increase in the cropping intensity that determines the level of the rate of return on investments in these projects. In the cases of the Gal Oya rehabilitation project and Kimbulwana water management project, 75 percent of the total benefits came from the increase in the cropping intensity and the remaining 25 percent from the reduction in the yield gap. In the case of Pimburettawa, the share was 100 percent. Among the indirect sources, we have some data for possible cost reduction in O&M due to better management. The level of O&M cost assumed in our analysis is Rs 740/ha in 1986 prices, whereas the actual government expenditure for this has been less than Rs 300/ha. Even if this "full" cost (Rs 740) is borne by the farmers so that the government can save scarce resources,[16] the resulting cost reduction is less than 40 percent of the benefit due to the reduction in the yield gap in the two cases above.

All this implies that the largest economic potential in water management improvement lies in the possibility of increasing the cropping intensity, followed by reduction in the yield gap through more equitable water distribution. If the potentials are to be realized effectively, efforts in water management research should be strategically directed to areas where the results of the research bring about an increase in the cropping intensity and more equitable water distribution to reduce the yield gap in irrigation systems.[17] Indicators of system performance should be related in some way with these two parameters. As far as economic performance is concerned, indicators that are unrelated to these parameters would be meaningless.

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[16] Our study in the Kimbulwana system indicates that the nonlabor O&M expenditures of high opportunity cost in this well-maintained system, through well-organized farmers' groups, are almost negligible (IIMI 1989).

[17] Crop diversification with high-value nonrice crops, if promoted successfully, could be another source of significant benefits. Note also that in this paper we do not deal with the issue of "institutional change" (in the sense of the IIMI Strategy), which would have a potential benefit.

How big is big? The potential or challenge ahead. We conclude that irrigation management improvement has a big economic potential. The size of this potential depends critically on how far system performance can be improved in terms of the two parameters discussed above — the cropping intensity and the yield gap reduction.

Figure 6 shows annual changes in the cropping intensity (rice harvested area base) of the major irrigation systems in the dry zone by season for 1960-87. In the last three decades, the cropping intensity has never reached 0.9 in the maha season or 0.7 in the yala season, the averages for the period being 0.79 and 0.51, respectively. How far can it be raised on a secular basis through water management improvement? Factors affecting it being many, it is difficult to predict a possible level. However, the following regression equations may give indicative figures:

$$CI_{maha} = \underset{(0.716)}{0.099} + \underset{(4.736)}{1.306}\, Rain_{maha} - \underset{(-4.514)}{0.612}\, (Rain_{maha})^2 + \underset{(4.100)}{0.083}\, D$$

$$R^2\ (adj.) = 0.534$$

$$CI_{yala} = \underset{(7.329)}{0.969} - \underset{(-6.985)}{0.243}(Rain_{maha})^{-1} + \underset{(1.566)}{0.219} Rain_{yala} + \underset{(2.185}{0.072}\, D - \underset{(-1.696)}{0.003}\, t$$

$$R^2\ (adj.) = 0.710$$

where; CI = the cropping intensity, Rain = total rainfall during the season in meters (in the case of the yala function, $Rain_{maha}$ = total rainfall during the maha preceding the yala season), D = dummy variable for the period after the Mahaweli water diversion to the dry zone (D=1 for 1978-87)[18], t = time trend (60, 61, ..., 87), and the figures in parentheses are t-ratios. The effects of rain on the cropping intensity could be interpreted as follows: in the maha season, rain during the season affects the cropping intensity positively, but too much rain reduces it; in the yala season, rain in the previous maha season, which determines the water storage of the tank at the beginning of the season, has a decisive impact on the cropping intensity with a certain maximum ceiling for it.

The maha function gives a maximum cropping intensity of around 90 percent for the period D=1, and the yala function yields the cropping intensity ceiling of around 80 percent for the late-1980s with average yala season rainfall. Thus, the past cropping intensity performance reveals the yearly cropping intensity of 1.7 on dry-zone major irrigation systems as attainable under the best conditions with rice as the crop grown. If good management could be a substitute for these best conditions, this would be the level of the cropping intensity attainable with rice. This is an increase over the present level by about 0.4. It may not be impossible to increase it further to a level of 2.0, an increase of 0.6 to 0.7 over the present level, if nonrice crops requiring less water can

[18] Note that the Mahaweli dummy has a positive significant coefficient for both the maha and yala functions.

be successfully introduced in the rice-based systems.[19] An increase of 0.6 for the existing irrigation systems in the dry zone (from 1.3 to 1.9 for major irrigation and from 0.8 to 1.4 for minor irrigation) is equivalent to constructing new irrigation systems, with the present level of the cropping intensity of a total command area of 200,000 ha, which is more than 65 percent of the present total command area of the dry-zone major irrigation systems.

As for the yield gap reduction, available data indicate that an increase of some 10 percent in the average unit rice yield for the system as a whole can be attained by this reduction due to water management improvements. If this is applicable to all dry-zone irrigation systems with an average rice yield of 4 mt/ha for major irrigation and 3 mt/ha for minor irrigation, together with the increase in the cropping intensity of 0.6, a rule of thumb calculation suggests that the expected income increase in real terms would amount to about 60 percent of the income presently generated in these systems, assuming that rice, and/or nonrice crops which give an income as high as rice, are grown. To the extent that nonrice crops giving an income higher than rice can be planted, an expected rate of income increase could be even higher than this level. It is no doubt hard to attain these targets, but this is the order of economic potential that irrigation management, and research therein, is challenged to realize in Sri Lanka.

[19] The Kimbulwana case gives the best example in this respect; by implementing a strict water rotation system, the cropping intensity was increased from less than 1.3 to nearly 2.0 on an average basis, with a third crop in some years (Gunadasa 1989).

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CHAPTER 2

Organizational Dynamics in a Corporate-Type Irrigation Organization: an Analysis of the National Irrigation Administration in the Philippines

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THIS STUDY SETS out to examine the internal dynamics or internal administrative behavior of irrigation organizations relative to environmental changes, policy changes, and clientele demands, and to explain how different types of behavior adopted by the organizations related to the performance or effectiveness of the organizations, and how they should be seen as a comprehensive study of organizational behavior.

Irrigation organizations, as most governmental agencies in their original setting in developing countries, were originally introduced or designed to be run as bureaucratic and welfare-dispensing organizations. If we look at the classic case of the *warabandi* system, water is allocated to farmers on a ration basis since available water can never be sufficient for the needs of all the farmers. It is the job of the organization to deliver the water according to the rationing principles, and it is then left to the farmers to utilize it in the best possible way. Under these circumstances, irrigation systems are organized to follow uniform procedures to ensure regularity, fairness, and reliability — the characteristics of the "machine type" of bureaucracy. However, the nature of demand, the condition of the physical structure of canals, and the nature of the social environment and social pressures have changed. In recent years some of the newer structures have been built to allow for more flexible responses to the demands of different types of clientele. Nonetheless, in most irrigation organizations, the basic structural or strategic changes or changes in style needed to relate to environmental demands have not taken place. Instead, the old bureaucracy has deteriorated; a new set of behavior has arisen and, instead of following or adhering to the original rules, selective use, and evasion or disregard of these rules has been practiced to meet ad hoc requirements or as opportunistic short-term responses. Under this scenario agencies could reap neither the advantages of machine bureaucracy such as precision, regularity, and fairness, nor the flexibility or responsiveness of market-oriented systems.

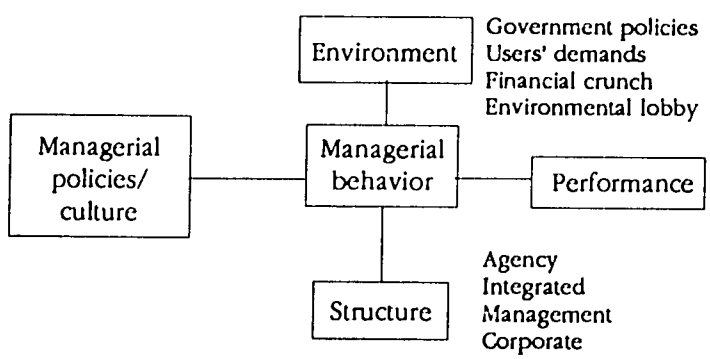
Recently, a movement towards introducing modern management methods has begun in some irrigation organizations. This "managerial mode" is defined as the

rational organization and management of work to achieve clearly defined objectives including their attendant motivational structure. This is different from the entrepreneurial mode, which adapts the organization to take advantage of the environment and capitalize on its own strength. The emergence of this mode in irrigation organizations is still too early to be visible at this stage. But government policies, financial constraints, the need for accountability and results, and increased participation and awareness of farmers are exerting pressure on agencies to adopt more managerial or entrepreneurial practices.

Some governments have also introduced new forms of structure to influence or change the behavior of irrigation agencies. The corporate form of organization introduced in the Philippines, or the integrated management methods initiated in India and Sri Lanka such as command area authority and river valley authority are examples of attempts to effect organizational change.

Certain administrative behaviors — bureaucratic, pseudobureaucratic, managerial or entrepreneurial — are considered as focal points of the study and they are related to variables such as environmental changes, including government policies, financial constraints, clientele pressures, donors' influence, changes in organizational structure such as integrated management or corporate form, and also prevailing management policies and management culture. The study will examine how different administrative patterns arising from differing mixes of antecedent factors in turn influence systems performance, which again react with the environments. This model, shown diagrammatically in Figure 2.1, is the basic frame of this study.

Figure 2.1. A model of management behaviour and performance in irrigation organizations.



Managerial behavior
1. Bureaucratic
2. Pseudobureaucratic
3. Managerial
4. Entrepreneurial

This study will be accomplished at two levels — inter-organizational comparison and intra-organizational analysis. It examines three different types of organizations, the corporate type, the project type, and the traditional departmental type as exemplified by the National Irrigation Administration (NIA) of the Philippines, the Mahaweli Authority of Sri Lanka, and the Irrigation Department of Sri Lanka, respectively. While the inter-organizational comparison will consider these three organizations, the intra-organizational study will concentrate on the work units or responsibility centers of the organizations. Many organizational studies take the macro approach; this approach, however, often fails to go deep into the internal workings inside the organizations. Our approach is based on the detailed study of how various work units and individual responses make up the various dimensions of the group process within the organization.

In the case presented here, the NIA of the Philippines, the organization functions in the context of a changing environment and adapts new managerial policies to suit this changing condition. In addition, we explain how different work units in the NIA, both at the headquarters and at the local level, perform in relation to these changes; why some units have adapted well to the new environment and policies, while others are failing to do so.

BACKGROUND AND SETTING

The National Irrigation Administration (NIA) was first established in 1964 as a corporation under an Act of the Philippine Congress. Essentially, it took over the functions of the irrigation division of the Bureau of Public Works. The development of NIA as a public corporation followed the trend where special-function agencies were created to operate development activities independently, unencumbered by the existing bureaucratic rules. The growth of public corporations increased with increasing finances — and also increasing governmental initiatives in the development process at that period. Although NIA was a corporate organization, it functioned initially as a department system because its cost of operation and maintenance was essentially financed by a general appropriation of the government, and not by its own resources. Even the fees collected were transmitted to the Treasury and the budget needed was appropriated by the Congress. In 1984, a fundamental change was initiated. The NIA was made to pay progressively for its own operation and maintenance costs, and collection of fees, sale of unused equipment, and equipment rental became the major sources of revenue for the NIA though there were special subsidies. Thus dawned an era of corporate financial decision-making with a substantial degree of independence and latitude. A further detailed policy for recovering costs was laid down in 1978. A new charter in 1980 gave NIA the right to charge an overhead of five percent on foreign loan accounts and construction projects carried out with foreign financial support.

In response to these changing conditions, a series of measures were initiated by NIA to achieve financial viability. These included the devolution of responsibility to the various administrative units (systems, in the case of field operation), and also to

regional office and central office departments and divisions. The operational national irrigation systems and provincial irrigation systems were treated as autonomous financial responsibility centers, each unit accountable for its own financial profitability. Measures to improve the collection of fees such as for parcellary mapping, close supervision and coordinating of collecting officials, as well as cost-cutting exercises such as selling obsolete equipment or eliminating unproductive operation sections were undertaken.

PERFORMANCE-ORIENTED APPROACH

In the NIA setting, the basic responsibility centers include national irrigation systems which operate the state-owned irrigation systems and also provincial irrigation offices responsible for construction and providing services to the communal irrigation associations. As these form the major revenue earners of NIA, the efficient running of these systems has become the priority of NIA's new strategy. Accordingly, NIA introduced an incentive system based principally on the financial performance of these responsibility centers. Every system manager in the national irrigation system is evaluated on the basis of four criteria. The score points for each System Manager for irrigation are:

			Points allotted (%)
1.	Operating efficiency		40
2.	Maintenance		20
3.	Collection efficiency		20
4.	Viability index		20
5.	Additional bonus points		20
	a) Operation index	6	
	b) Collection efficiency	6	
	c) Viability index	6	
	d) Report submission	2	

The operating efficiency has two indices: 1) irrigation intensity of dry and wet seasons, which is given 30 points; and 2) irrigation system efficiency index, essentially the efficiency index of the water distribution system (demand for water divided by supply of water) which is given 10 points.

Under this system, the maximum of 10 percent of the net earning or income is entitled to the system which performs well in these indices. In measuring the performance itself, the financial factors — collection efficiency (20 points), viability index (20 points), extra bonus points (12 points) — were taken into account: a total of 52 points in the bonus points system of 100 points.

As other measures such as the water distribution efficiency index and the maintenance efficiency index include many approximate and judgmental items, the results of these measurements will not probably be sharp enough to discriminate much between the systems. Consequently, the financial indices based on hard data such as the collected revenue and expenditure necessarily become the backbone of the performance measures.

IDENTIFYING THE PROBLEM

We now have to examine the relationship between performance and various organizational factors in responsibility centers. Under the circumstances of change and dynamism, irrigation systems in the Philippines give us a very good opportunity to question or examine the supposed relationship between performance and organizational and environmental factors. The problem in the Philippines is that although the viability index has been in operation for about six years there are still many systems which barely survive or which are below the expected performance level of recovering its operating costs. In many systems a situation of financial nonviability persists. Therefore, NIA was greatly concerned with raising the productivity of low performing systems. A number of explanations are given for this low performance. It has been pointed out that some systems are not successful because their sizes or service areas are not sufficiently large and, therefore, an economy of scale cannot be reaped. On the other hand, it is also often posited that variations in system performance are mainly due to the scarcity of water or rain during the summer months in parts of the Philippines. The systems in the Philippines provide more or less sufficient secondary irrigation during the rainy season, except for a few weeks in which irrigation is needed. However, in the dry season agriculture is almost entirely dependent on irrigation. As the amount of water available during the dry season determines to a great extent the area that could be farmed during the season, systems which have an insufficient amount of water during the dry season are unlikely to achieve any level of viability performance. It should also be noted that in the dry season irrigation service fees can easily be collected because users are ready and willing to pay for water which they cannot otherwise obtain. Alternatively, some have pointed out that yield is another important factor in indirectly influencing the viability of the systems. Farmers producing high-yielding crops with resultant high surpluses can afford to pay irrigation fees, but those in areas where the yield is lower, find it difficult to pay irrigation fees.

These are some of the conditions highlighted as causes of variation between low and high performing systems. In addition, we have also observed that there exists, in almost every system, an intense management activity towards the end of the season. We also suspect that, since collection of fees and reducing costs are directly contributory to financial performance, any factor which in turn promotes these conditions will be very important from the management point of view. The effective revenue collection and cost-reduction being highly management-intensive, they naturally demand appropriate organizational development and changes. It is likely that styles of management and organization practiced in some of the high-performing systems will be different from the low-performing systems as each center manager attempts to effect the desired changes. In other words, the managerial styles, organizational tactics, and practices could also be importantly related to financial performance variations in these systems.

Because of these reasons, we hypothesize *that the financial viability of the system may depend on a number of conditions which include both physical and managerial factors*. As NIA is one of the organizations that maintains a good information system, we could verify the importance of physical factors on the basis of available information.

Data on management factors and managerial profiles had also been collected in our research. In consequence, examining these factors and also unraveling the detailed workings of the management system itself will likely highlight the causes of variation in the financial performance of these systems.

Of course, we acknowledge that an evaluation of the performance of irrigation systems should include criteria other than purely financial success. For example, the sustainability of the system, the satisfaction of users, the reliability and adequacy of water supply, and environmental impact are other criteria that are to be looked at in analyzing system performance. However, we are concentrating here on the use of the viability index as a measure of performance. The reasons are obvious. As management itself introduces the viability index as an important criterion, because staff themselves are rewarded on these financial criteria and all activities are directed towards achieving this objective, we use this as a focal point for our study. In addition, in the context of financial independence, financial viability itself is a good indicator of the efficiency of management systems.

Financial viability depends on two variables, revenue and costs. In addition, the collection of fees will most likely be correlated with the service provided by NIA. Unhappy or unsatisfied farmers are not likely to pay for the use of the service. The fact that the collection rate is high in a particular system is partially attributed to a higher level of service achieved in that system. All these factors point out that the study of financial viability as a focal point is desirable and meaningful in this context.

METHODOLOGY

A selected number of sample systems, roughly forming one third of the total systems in NIA were surveyed. The data collected was the result of a structured questionnaire and economic and general information gathering from existing records and reports. The questionnaires invited information about how the systems determine their objectives, who influences the process, and an evaluation of the performance of the supervisor and staff members in each system. In addition, these questions covered various management processes such as information and activity flow, the chain of command, organization of work, different types of motivations applied, different management styles including the group process, individualized management, and the interconnections between systems and other units in NIA itself or with outside units. All these variables provided information to gauge the relative importance of both physical factors and managerial factors which existed in these systems. Conditions relating to each of these categories were correlated with the final financial performance. The questionnaires included different sets of questions, each to be answered by different respondents such as supervisors and members of the work unit.

To analyze large magnitudes of data thus compiled, data reduction and the construction of appropriate indices comprising answers to different questionnaires were used. Item selection for each scale was done on the methodology developed by early research. This research used questionnaires and methodology designed by the Organizational Assessment Centre, Wharton School of Commerce of the University

of Pennsylvania. Such questionnaires had already been applied to various types of service organizations, including the various scales and subscales of important management categories. We adopted these scales and the rationale used by the earlier research as a starting basis for constructing the scales.

In addition, we improved the indices by studying how our own data actually appear with respect to categories. Each question included in each of the subscales was factor-analyzed and the factor scores for each category used as an alternative scale. When factor analysis was used, coefficient theta was applied as a reliability index and the cut-off rate for acceptance of any scale was 0.80 or thereabouts. Resultant scores for both methods were analyzed to ascertain differences between the various sets of systems or between more-viable and less-viable systems or between the various levels of employees or various types of employees within the subsets of the organization.

SAMPLING

As we defined performance as one category of analysis, we selected three regions in NIA representing different levels of system performance. Region III in Luzon was considered a lower performing group whereas Region XI in Mindanao was considered as the best performing group, while Region VI in Iloilo was taken to represent medium-level performing groups. From each region, Provincial Irrigation Offices and the National Irrigation Systems were selected, and from each system five to seven respondents including the supervisor or the superintendent of the system, the engineers, and other officials, including watermasters, were assigned to answer a different questionnaire designated for each category of respondent. The superintendents answered the Supervisor Questionnaire, and the members of the group answered the Member Questionnaire. The Job Design Questionnaire was answered by one or two other members of the group. The Focal Unit Questionnaire which examines interrelationships between the responsibility centers and other units or outside agencies was answered by the second in command of the systems or work unit, and one of the watermasters answered the Water Distribution Questionnaire. In constructing the scales, various items from the questionnaires were combined to represent an average situation of each system. Table 2.1 describes the types and number of the work units selected.

Table 2.1. Type and number of work units selected.

	Central office	Regional office	NIS	PIO
Sample	35	23	36	16
Total	70	63	95	67

NIS = National Irrigation Systems.
PIO = Provincial Irrigation Offices.

A total of 110 responsibility centers or work units were selected in these samples. These included 35 divisions from the central offices and 75 work units from the field. The 75 work units in the field comprised 36 National Irrigation Systems, 16 Provincial Irrigation Offices and 23 divisions of Regional Headquarters Offices. The total number of work units selected from the National Irrigation Systems and Provincial Irrigation Offices was approximately 30 percent of the total number of systems and 25 percent of Provincial Irrigation offices. In the case of regional offices, there were usually five to six divisions and all of them were selected. In the case of the Central Office, approximately 50 percent of responsibility centers or work units were selected. In other words, the samples formed a fairly large percentage of the total universe. From each system or Provincial Irrigation Office, six to seven officials (forming the bulk of important members of the staff in these systems) answered the questionnaires. Approximately 700 questionnaires were collected in the survey, in addition to data from existing records and from field interviews with various officials in these systems.

Table 2.2 describes the characteristics of sample irrigation systems. It will be noticed that among the three Regions, Region III, Region VI and Region XI, the average size of the system varies from 3,400 ha to 7,400 ha. The median is between 4,000 ha and 5,000 ha. However, the Upper Pampanga River Integrated Irrigation System (UPRIIS), a reservoir system in the Pampanga Valley, includes four systems with an average size of 25,000 ha. Unlike other systems which are only run-of-the-river systems with a small service area, the system in the UPRIIS forms part of a large river valley project which uses the reservoir system. Apart from Region XI, all other regions have similar patterns in percentage of actual to programmed irrigated area in the wet season or the actual to programmed irrigated area in the dry season. The collection efficiency and viability index in Region XI are definitely superior. An observation may be made: several basic characteristics such as average size, the cropping intensity ratio of rice to other crops, and farm size do not really differ between regions.

RESEARCH FINDINGS

In identifying the problem the following two hypotheses were made:

1. Variations in performance are to some extent influenced by physical and economic factors which are beyond the immediate short-run control of the system managers.
2. Variations in performance of an irrigation system in relation to the viability index is greatly influenced by the way in which the system management is organized, operated, motivated, and accounted for.

In regard to the first hypothesis, the following are identified from the available data as plausible physical explanations for the variation in the system performance:

- The service area of each system.
- The size of the landholding.
- The average yield per hectare.
- The percentage of rice crop to other crops.

Table 2.2. Characteristics of the sample irrigation systems as at end of 1989.

	Region III	Region VI	Region XI	UPRIIS
1. Total service area (ha)	67,179	53,500	38,370	100,781
Average service area per system (ha)	7,464	5,944	3,488	25,195
2. Irrigated area (ha)				
a) Program	53,067	46,783	27,426	91,544
Wet season	50,893	43,108	31,272	85,787
Actual/program (%)	(96)	(92)	(114)	(93)
b) Program	41,808	30,293	25,352	65,077
Dry season	41,969	31,944	29,097	68,567
Actual/program (%)	(100)	(105)	(115)	(105)
3. Benefited area (ha)				
a) Wet season	48,437	41,766	21,445	72,819
b) Dry season	40,900	29,297	24,223	53,261
4. Cropping intensity				
a) Program	141	144	138	155
b) Actual irrigated area/service area	138	140	157	153
c) Actual benefited area/service area	133	133	119	98
5. Collection efficiency				
a) Program	72	70	83	76
b) Actual collectibles/estimated collectibles	44	50	81	32
c) Actual collectibles/collectibles based on benefited area	52	50	86	42
6. Viability index				
a) Program	0.97	1.54	120	2.19
b) Actual	0.79	1.22	188	0.99
c) Actual/program (%)	81	79	156	97
7. O&M Cost/ha (P/ha)				
a) Expenses/service area	415	291	275	339
b) Expenses/total benefited area	312	219	231	271

- The cropping intensity.
- The area cultivated in the dry season as percentage of service area.

Among these variables, the service area of the systems addresses the question of economy of scale. The implication is that larger-size systems or systems with a greater service area could utilize overhead staff or overhead costs more effectively or spread the overhead costs over a larger area served. It is also likely that because of their larger size, bigger systems may be able to afford a specialist, special service or equipment for their use.

The size of the landholding, on the other hand, is related to the ability of the consumer to pay. It is reasoned that the owner of the larger-size farm will enjoy a

greater agricultural surplus and, therefore, is more likely to be able to afford the irrigation fees.

Likewise, the average yield per hectare contributes to the income of the farmer. A farmer with higher yields should be able to earn more, accumulate more surplus, and accordingly be more willing or at least more able to pay for irrigation fees.

In addition, the percentage of rice crop to other crops also indicates the income level of the farmers. The farm which grows crops other than rice, such as banana or sugarcane will be more profitable and the farmer will be willing to pay irrigation fees, determined essentially on rice yield, that is imposed at a comparatively lower rate.

The cropping intensity is yet another indicator of how effectively irrigation water is utilized or how available water is. The greater the cropping intensity the greater the number of users or the area used, and more likely will be the collection of revenue — although irrigated area and the revenue collected have never been clearly correlated in many parts of the world. The area cultivated in the dry season as a percentage of the total area is a proxy variable for the availability of both rain and irrigated water in the dry season. It has been argued that in regions where rain is even throughout the year the cropping area and also the yield in the dry season will be higher. In fact, all these explanations are usually given by system managers when asked why their own or a particular system performs less than what is expected.

To test these suppositions, these variables are utilized as independent factors in a regression model which uses the viability index as a dependent variable. None of these variables are related significantly to the dependent variable. The relationship between each of these variables and the dependent variable, the viability index, is, surprisingly, almost zero. Why these factors have no influence on the viability index needs to be examined. However, a careful look at the nature of the viability index, and also the general characteristics of these systems will probably give us plausible reasons for this finding. For instance, certain system characteristics such as size of the systems, the cropping intensity, and farm size are more or less the same in all the systems except in the four systems of UPRIIS which are large-size reservoir systems. As the sample itself is fairly uniform it will be difficult to discriminate between the significance of the physical factors in systems. In other words, physical factors are controlled or considered constant to a large extent in the Philippine setting. Systems are all run-of-the-river small systems, managed by four or five engineers and their assistants, where more or less very similar crops are grown, and which are subjected to more or less uniform vagaries of climatic conditions.

It should be noted that the systems performance which we have defined here as a dependent variable has a very limited scope. In effect, we presume that physical factors have no influence in the Philippines, that is, performance indicators defined as the viability index, and the physical factors, are not really related. It does not, however, preclude the fact that physical factors may have influenced the distribution of water, or the maintenance and sustainability of the system.

It should be realized that the financial performance indicator is based on revenue collection and expenditure. Achievements in revenue collection could be more a result of management activity than a result of the ability to pay. According to a study by Small, it was found that farmers in most Southeast Asian countries could pay limited

irrigation fees, or a limited but fairly decent coverage of the actual cost of maintenance. If it is the case, the question will be whether legislation, conventions, and management practices could be influencing factors for farmers' actual payments. Likewise, the amount of expenditure could be quite independent of any physical factors that have been mentioned and, therefore, it should be proposed that the viability index be more a management function than a physically related variable. In consequence, the influence of physical factors on the index, especially in the case of uniformly comparable systems, is minimal. It should not, however, be inferred that the physical factors are unimportant in all cases. This only indicates that under certain contingent or limiting conditions the physical factors may not be significant in relation to certain aspects of the performance data.

On the other hand, very surprising results are found when financial performance is related to management variables. These results are found in the organizational questionnaires answered by the supervisors and members through a set of questions which relate to how work units are organized. All are related to important aspects of the ongoing management process within the system management itself. Questions include such categories as, "how are the objectives determined?," "how are the specific targets set?," "how precisely are objectives determined?," "how is consensus on the performance reached?," and "who influences the decision making?" When these management questions are related to the financial performance variable, it is found, surprisingly, that fifteen questions relating to various management variables account for 89 percent of the variance in a regression model. The slopes representing all these factors, individually, are also highly significant in statistical terms. This gives us a very strong indication that management factors are very significant in explaining financial performance.

If we look at the significant cluster of items, four important variable clusters can be identified. A number of items are related to clarity, approval, or the consensual aspects of performance criteria; another group relates to information flow, another set to incentives, and the last set to conflict and conflict resolution. Clarity and consensus of performance standards and collective influence on enforcing the rules are influential in enhancing the viability scores. This is not surprising because in any result-oriented system, the clear definition of results and the acceptance of criteria are important preconditions or prerequisites for success. On the other hand, not following through the chain of command, the acceptance of an independent work flow, and intense interactions between supervisor and employees, indicate that a more interactive but less formal management operates in successful systems. It is interesting to note that the idea of group and consensual decision making is not significant. Nor is the group process or Japanese type of management significant here. Again, it is also found that the frequency of occurrence of conflict among members and the need for conflict resolution by the hierarchy also increase commensurate with more management activities in the successful systems.

A clearer definition and acceptance of performance, and a more directive leadership but with high interaction with members of the groups seem to be the criteria of success when evaluated in terms of financial viability. The high intensity of occurrence of conflicts and conflict resolution serves to reiterate the highly tense nature of the

atmosphere under these circumstances, as well as the more direct leadership which further heightens these tensions. These are, in fact, characteristics of management in a high-tension setting in the business world.

This information will contribute to the decision making on what kind of management systems are to be prepared to enhance the performance of national irrigation systems. Our findings indicate quite differently from the usual text book advocacy on human relation or the permissive type of leadership styles. Here, decisive leadership coupled with the appropriate intensity of interaction, the ability to sidestep some work rules in the context of clarity of objectives, are all at work in successful systems.

Our findings are of necessity preliminary as we are using only the single item variables. When single item variables are combined into various meaningful indices through factor analysis, we still find the same patterns or styles remaining operative although the significant levels as well as the total amount of variance explained are reduced. But unmistakably the same pattern persists. This indicates that performance-related organizations, effective management styles, and management process are unmistakably very important. Any organization which can effect or which can activate and put into motion this kind of process is likely to be effective.

The comparison between the Provisional Irrigation Offices and the National Irrigation Systems as well as how they differ from Headquarters and how NIA as a whole operates as a management system are still to be explored. Further results will be interpreted in a larger context and especially in relation to the findings from the other two organizations in Sri Lanka. When all findings from these are compared, a more comprehensive and definitive picture should appear.

PROBLEMS AND DYSFUNCTIONS OF PERFORMANCE MEASURES

This research indicates how effectively systems are organized to achieve the overriding objectives of financial viability and to explain some of the probable reasons why some systems perform better than others. This is not the whole story of the management process. As an organization attempts to direct all its activities on a particular or a narrow set of objectives, what consequences might follow from neglecting other objectives, plausible or desirable but obviously not emphasized at the moment, and what the dysfunctions of performance measurement in use are, are questions one might want to raise.

The questions of adequacy and reliability are never explicitly paid attention to. There is the irrigation efficiency index which more or less follows the standard procedure for calculating water demand and supply. Supply is calculated on the basis of the amount diverted at the diversion gate and fixed parameters such as conveyance efficiency and distribution efficiency. Likewise, on the demand side, in calculating the water requirements, the numbers of days and areas under land preparation and under crop maintenance could be considered as the only operating variables. Other factors are fixed parameters, precalculated years ago for the whole region or the whole country. As, essentially, these are the only variables management can influence, a

much simpler formulation which can be broadly compared in-between time in the seasons would be more useful to the system managers than the formula included in the incentive scheme. Since this system efficiency index forms only ten per cent of the total score in the bonus calculation, the whole exercise probably serves only as a ritual. It is most likely that almost every system obtains similar scores in this portion of the bonus index.

We have seen that the viability is the composite function of income and cost. To improve the ratio, the manager will be tempted to reduce various costs in the financial statements. This in itself is a very good idea indeed, leading to the development of a cost-conscious manager. If so, well and good, the results will be entirely positive. However, zeal in cutting down costs could also lead to cutting expenditures which, while improving the ratio, will produce undesirable consequences in the long run. For instance, cutting off O&M expenditure and postponing visibly postponable but potentially damaging maintenance programs will have disastrous effects in the long run. Independent observers complain that the maintenance of systems in the Philippines needs to be kept up. The trend in O&M expenditure itself, between 1983 and 1989, adjusted for inflation, is actually declining, indicating the seriousness of the problem.

The next question is revenue. Revenue is a function of collection efficiency, again dependent on the irrigation area or benefited area. An improvement in ratio could be entirely attributed to management efficiency if the absolute area of irrigated or benefited area is kept constant. Here again, there is a loophole that the ratio can be improved by manipulating the collectibles dependant on benefited area. The problem is already recognized, and attempts have been made to compile detailed parcellary maps for each system so that irrigable area and benefited area can easily be identified. In addition, a limiting feature in the bonus indices is that the cropping intensity and the collection efficiency are, in a way, opposite to each other in their effect. Improvement in the cropping intensity will likely lead to the larger benefited or collectible areas. Consequently, it will demand an improvement in the degree of collection efficiency on a larger area. In other words, with the increase in the cropping area adversely affecting the collection ratio, the manager has to balance between two contrary demands to maximize his benefits. Looking at which will give a better incentive bonus, increasing crop area or improving the ratio by management methods, is a question he must decide upon. How the manager actually behaves still needs to be studied on the basis of records of achievement. It is also possible that since we are examining ratios, not absolute amounts, the optimal ratio may be found without substantially improving the physical volume of area. In effect, with a smaller base and smaller area initially, a high ratio could be maintained without much real improvement. These are the hazards of the total reliance on a single set of performance criteria in this context.

One of the more important problems in this type of management is the sustainability of the approach in the longer run. This is particularly evidenced in the case of Provincial Irrigation Offices (PIOs). While revenues and expenditures in state-owned irrigation systems are more or less stable from year to year, the provincial systems' revenues are very much dependent on the cycle of construction activities. Provincial

Irrigation Offices receive their revenue on the basis of construction activity as well as from the recovery of cost from farmer organizations for the completed and transferred systems. At present, payment includes initial equity payments as well as yearly amortizations. These are the main sources of funds coming to the Provincial Irrigation Office. Recently, management has also introduced, as an alternative, outright payment of 30 percent of the cost of the project as equity which will thereafter absolve farmers' organizations of any responsibility for further payment. The outcome of all these conditions is that as long as construction activities are going on and new activities are added, revenue will be high. However, as the cycle of construction activity slackens on the basis of the availability of the funds under different administrative and political conditions, it will be very difficult to keep the finances of PIOs in balance over the long haul. In some years there would be a flurry of construction activities resulting in high income followed by lean years. It may also be difficult to extract the same quanta of payments from the farmers in the later stage of repayment as systems become old or deteriorating. On the other hand, expenditure is more or less fixed because Provincial Irrigation Offices are construction-oriented organizations with high fixed costs. There will be a number of engineers responsible for overseeing construction activities and also many other administrative activities are more or less fixed. In other words, with the high fixed expenditure, coupled with a highly unstable or variable structure, the viability of the Provincial Irrigation Office system in the long run is in doubt, so NIA will have to think through this problem more carefully for future re-organization.

CONCLUSION

Management targets are directly and importantly related to the variation of the financial performance of systems. The management system which typifies successful systems in the Philippine setting compromises more directive leadership with some flexibility to go beyond normal rules, backed up by more definite support for objective criteria and group incentives and processes, with more permissive, human-oriented, or consensual leadership.

CHAPTER 3

System Turnover to Farmers in the Philippines

Leonardo S. Gonzales[†]

IN THE EARLY 1970s, the National Irrigation Administration (NIA) of the Philippines became seriously concerned about problems of irrigation system operation and maintenance. Service areas of its irrigation systems were not being fully irrigated and the irrigation fees being collected were far below the operation and maintenance (O&M) costs. The phasing out of subsidies for O&M of the national irrigation systems that NIA administered posed another big problem. NIA realized that it would need to organize irrigators' associations capable of effectively carrying out the partial or full management of the O&M of irrigation systems.

In 1976, NIA initiated two pilot projects to organize farmers into irrigators' associations. It hired irrigation community organizers who were college graduates and experienced in working with the rural and urban poor, able to communicate with farmers and dedicated to the participatory concept. This was implemented in two communal irrigation projects, to maximize the participation of farmers from the grass-roots level in all undertakings within the irrigators' associations. These pilot projects developed the basic processes for inducing farmers' participation, in spite of some problems encountered in their implementation.

NEW APPROACH

Having achieved encouraging results in communal irrigation projects, NIA turned towards national systems and in 1983, a similar approach with a new concept was piloted and initiated in the Angat nit Argat-Maasim Rivers Irrigation System and the Porac-Gumain Rivers Irrigation System in Region 3, in the provinces of Bulacan and Pampanga in Luzon. Entitled the Farmer Irrigator Organizer Program (FIOP), the new approach requires the utilization of farmers in organizing co-farmers into irrigators' associations.

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To ensure smooth implementation of the new approach, NIA created the following teams or groups:

Project Management Team

This team was composed of the NIA Regional Irrigation Director as de facto head, the Manager of the Institutional Development Division as the Project Officer and the Chief of the Operation Division, the Irrigation Superintendents and the Farmer Irrigator Organizer Supervisors of the two pilot systems as members. This team was responsible for the conduct of the Project Management Team meetings, monitoring and evaluation of the program and the submission of monthly progress reports.

The Supervisory/Organizing Group

This group was headed by the Irrigation Superintendent (Chief of system) who directly supervised and coordinated all FIOP and O&M activities of the system, validated farmers' demands and conducted coordination meetings at least once a month. Under him were the following personnel:

- Water Management Technologist/Watermaster: Assigned to assist in FIO (Farmer Irrigator Organizer) identification, assist FIOs in validating the list of farmers and identification of irrigation system problems.
- FIO Supervisor (FIOS): Directly supervised the FIOs in organizing activities and prepared monthly progress reports of activities.
- Farmer Irrigator Organizers (FIOs): Conducted house visits, making contacts and identifying problems, and created farmer awareness of collective problem-solving.

The selection of the FIOs was made on the basis of their leadership potential, availability, age, educational attainment, economic status, etc. Selecting a farmer organizer that fits all the qualifications set forth was a very difficult task. A farmer may be good in oral communication and be well-respected, but he may not be able to read and write. Whatever difficulties there were in the FIO selection, the Watermaster was instructed to choose and submit the names of the best three farmers he knew in each deployment area.

TRAINING

When all the FIOs were selected, a pre-deployment training was given during May 2-7, 1983, at the NIA Training Center in San Rafael, Bulacan. The objective of the training was to acquaint and familiarize each of them with all aspects of organizing work, their area of deployment and possible problems to be encountered. Trainees were given parcellary maps showing areas under their jurisdiction, together with the list of farmers in each area. Some of the topics discussed during the training were: orientation of the

FIOP; present status of the system and its operation; decision making; guides and steps in organizing the irrigators' association (IA); and farmers' problems in irrigation and suggested solutions. The topic on farmers' problems in irrigation and the corresponding solutions produced very lengthy and productive discussions. It was at this point, that the FIOs realized the importance of farmers' participation in the O&M of irrigation systems.

Having completed the six-day training, the FIOs went to work. The first month of actual organizing had no results at all. Farmers were always saying that they were fed up with NIA. Ever since the irrigation system was constructed, they had brought their problems to NIA which had not taken any action. These problems were then brought to the attention of the Irrigation Superintendent (IS) during the coordination meeting. The IS immediately inspected each area of the FIO to investigate and validate farmers' problems. Knowing their needs, he talked to the farmers about a joint undertaking. The NIA would provide all materials needed and the farmers would provide free labor. After getting the consensus of the farmers, the Superintendent facilitated the delivery of construction materials or equipment needed, even without having a program of work and funding support. Seeing the arrival of a NIA truck loaded with construction materials on the agreed schedule or soon thereafter, the farmers were greatly motivated. The FIOs were instant local heroes. The farmers believed in them and saw that NIA was serious this time. The FIOs then started organizing small groups of farmers called BSM (Buketeng Samahan ng Magpapatubig in the Tagalog dialect, meaning Farmers' Irrigators' Groups).

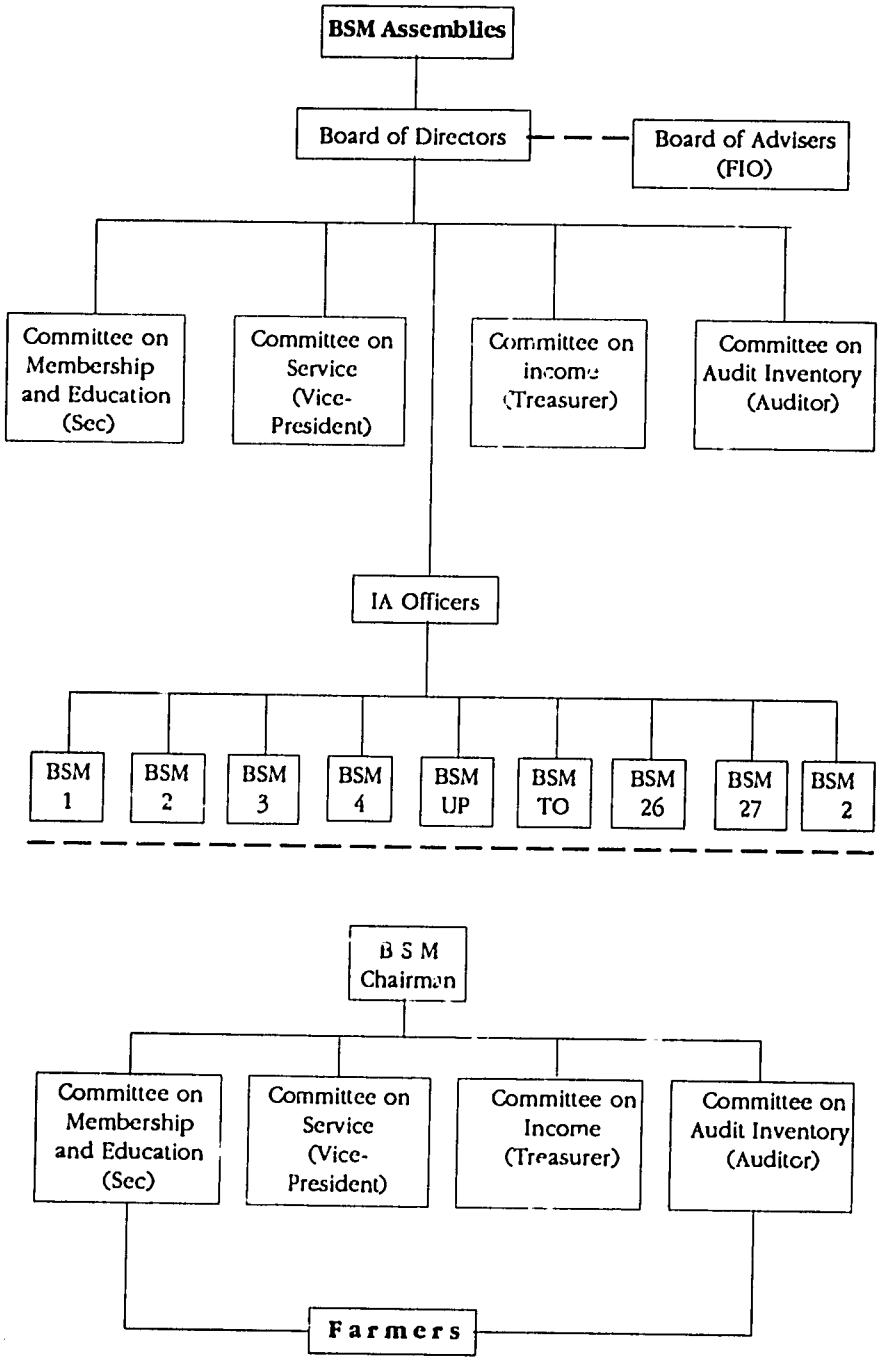
IRRIGATORS' ASSOCIATION

During a seminar workshop, on October 6, 1983, (five months after the FIO pre-deployment training) the Bustos Pandi Extension Pump Irrigation System became the Bustos-Pandi Irrigators' Association Incorporated, or BUSPAN IA, Inc. The Chairmen of the 28 BSMs (or FIGs) formed the IA. FIOs attended the seminar. In the workshop, the bylaws of the association were formulated, improved and revised. The 28 BSM Chairmen were installed as the Board of Directors (BOD) of the association and from the BOD, they elected their sets of officers. They created four committees to handle various activities of the association. Figure 3.1 shows the organizational structure of the irrigators' association.

Officers elected from among the 28 BSM chairmen were as follows:

- President: Acts as the head of the IA. He is responsible for all IA business transactions.
- Vice-President: Two vice-presidents are elected. The first vice-president is the chairman of the committee on service while the second vice-president acts as co-chairman. They are responsible for overall water distribution within the IA.

Figure 3.1. Organizational structure at the IA level (upper box) and at the BSM level (lower box).



- Secretary: Acts as the chairman of the committee on membership and education. He is in charge of the follow-up activities for training and application of new members.
- Auditor: Is the chairman of the committee on Audit and Inventory. He is responsible for checking financial transactions and for all properties acquired by the Association.

At the BSM level, the same sets of officers are elected with only one vice-president. Prior to the monthly BOD meeting, a monthly BSM meeting was also held. They discussed problems affecting their operations and all unresolved issues were raised to the BOD level for decisions. Once agreement or a decision is made at BOD level, this is brought down to the BSM level for implementation. The role of the FIOs has become advisory as they are permanently installed as the Board of Advisors (BOA). They attend the monthly BOD meetings and also give guidance and attend meetings at BSM level when requested to attend.

CHANGES FOLLOWING TURNOVER

Thirteen months after the FIOP was initially launched (out of the projected 30 months of implementation), in June 1984, the BUSPAN IA Inc. took over full management of the operation and maintenance of the pump system. Even during the organizing phase of the project, significant changes occurred. As the IA were given training on system management, power consumption started to go down (see Figure 3.2).

By teaching simple water management practices such as the closing of openings to the rice fields when they are already full of water and preventing water going to drains, the BUSPAN IA was able to save on power consumption. They were able to save 79,000 kwh from 1983 to 1984. Even in 1987, due to the late rainfall, they operated the pumps in the wet season as though it was a dry season. They were able to save 7,000 kwh, compared with the 1983 consumption.

Another area of significant change was the collection of the irrigation service fee. The BUSPAN IA, through NIA guidance, had increased the irrigation service fee from 8 cavans of unmilled rice (one cavan = 50 kg) to 10.5 cavans for two cropping seasons (wet and dry).

As shown in Figure 3.3, the average collection percentage for wet and dry seasons during NIA management up to 1983 was about 50 percent. Starting in 1984, when BUSPAN IA Inc. took over the collection, efficiency never went below 90 percent. They attained a 100 percent collection in 1989 and are trying to maintain it at that level.

There are several other changes worth mentioning. At present, farmers seldom interfere in the operation of the pumps. If they do, they inform the committee on service of their needs, so that the committee can make the necessary adjustments. Almost all farmers in each sector knew each other. Previously, a dispute could lead to a heated argument or even a fist fight and loss of life. Today, farmers request each other to stand as sponsors in the baptisms or weddings of their children. As a result of their coordination, farmers receive an equal distribution of water, resulting in increases in individual crop production.

Figure 3.2. Graph showing power consumption under NIA Management in 1983 and under BUSPAN IA starting 1984.

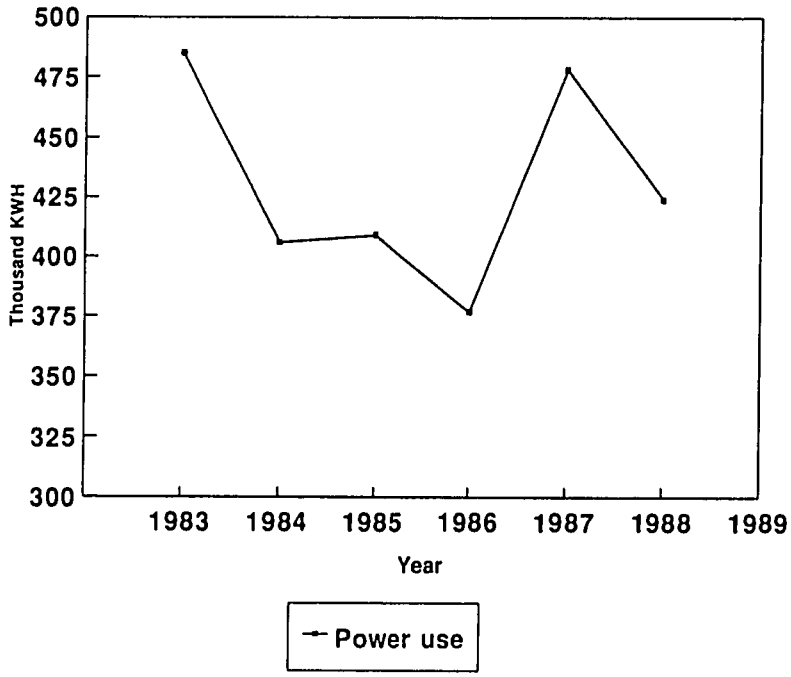
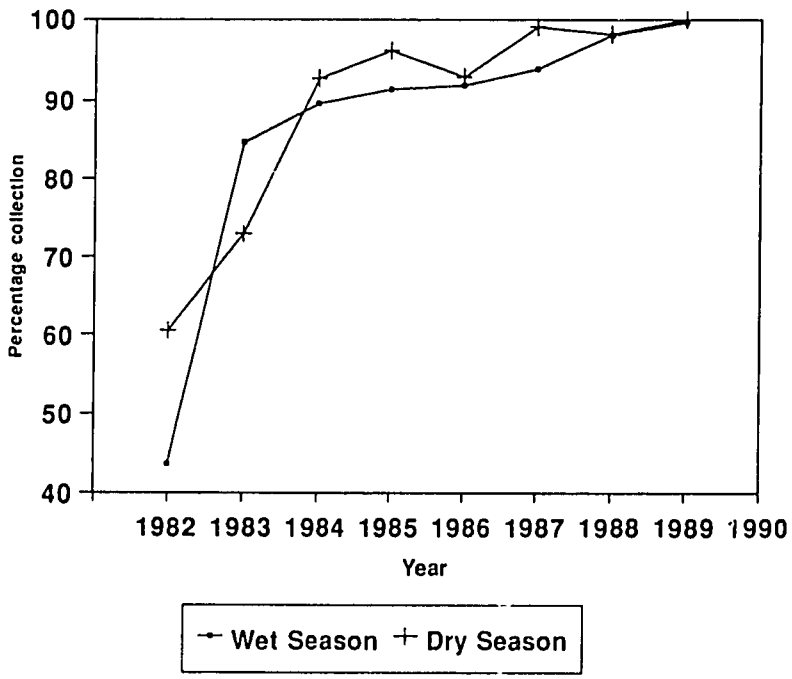


Figure 3.3. Graph showing collection percentage during NIA management up to 1983 and under BUSPAN IA starting 1984.



FIOP NATIONWIDE

Following encouraging results from the initial implementation in Angat nit Argat-Maasim Rivers Irrigation System (AMRIS) the NIA Top Management decided to implement FIOP nationwide. In mid-1988, a World Bank assisted project, the Irrigation Operation Support Project (IOSP) was started in all the twelve regional offices of NIA. It involves the rehabilitation and improvement of all national irrigation systems in the country. The project includes the accelerated development of irrigators' associations in all national systems. As a result of this, the entire regional institutional development staff of Regional Office No. 3, all staff of the AMRIS, all FIO supervisors and officers of BUSPAN IA Inc. were invited as resource speakers in the training components of this project. They traveled from Region 3 to Region 2 in Cagayan Province, and as far as Region 5 in Bicol province in Central Luzon. They even took a plane to Region Ten in distant Cagayan de Oro in Mindanao to share their experiences. One of the farmer organizers said that he could not believe what was happening. He never expected in his entire life that some day he would be able to fly in a plane. Yet it happened.

There was a great deal of apprehension among the Board of Directors of the IA during the final discussions prior to the signing of the turnover agreement. They were unsure whether they could efficiently manage the operations of the pump system. There were so many questions of "how" and "if" from the farmers. However, the NIA managed to convince them that it would always support and guide them in their operation, emphasizing the need for their participation. In the end, the farmers agreed to take over the pump operation for a one-year trial period, from the wet season cropping of 1984 to the dry season cropping of 1985. By the end of the wet season cropping of 1984, they realized that they had reduced the power consumption and increased the collection to produce a surplus income of one hundred thousand pesos. The rest is history.

Management Training through Special Awards

Zenete Pelxoto Franca

BACKGROUND

IN THE COURSE of its work on promoting and disseminating improved irrigation management practices, IIMI has recognized the existence of field practitioners who take risks to develop and test management techniques which produce successful results, but which are not disseminated to the irrigation audience either because of the lack of opportunities and/or abilities to record their experiences, or because of a lack of support, interest and even recognition on the part of the agencies for which they work.

IIMI has therefore created the Special Awards Program, a direct training method that provides opportunities for irrigation professionals who have developed successful innovative approaches to irrigation management problems to pass on their experiences to others by documenting and publishing them as case studies.

This program provides participants with an opportunity to spend between two and four months at IIMI headquarters or at one of its field locations, and to record their experiences under the guidance of Institute staff, who assist participants in formulating their ideas and approaches. IIMI provides awardees not only with allowances to cover their expenses but with substantial assistance in developing their field-level experiences into case studies.

By 1989, IIMI had provided three such awards to irrigation managers from Sri Lanka and the Philippines. Their experiences have covered organizing irrigators' associations to improve system operation and maintenance, farmer participation in the rehabilitation of a small system, and promoting coordination between farmers and agency officials in irrigation system management. As part of the Special Awards Program, in 1990, an irrigation professional was selected and invited to write a case study on his successful experience in the Philippines in turning over of a pump irrigation system to a farmer's organization. IIMI has found the Special Awards Program to be very useful in exposing real problems in irrigation management and the processes by which responses to these situations are developed. The case studies enable IIMI both to learn about innovations that do not result from its own research efforts and to

disseminate them — a function envisaged within the Institute's mandate. IIMI is interested in expanding this program and with it the base of information on management innovations tested in the field.

SPECIAL AWARDS AS A MEANS OF PROFESSIONAL DEVELOPMENT

The Special Awards Program provides an element of training in assisting irrigation managers to develop themselves professionally. The program recipients are usually irrigation practitioners who are mainly field-oriented professionals without opportunities to diversify the development of their knowledge and skills in different areas of concern.

IIMI's program contributes greatly to the professional development of the recipients of Special Awards, providing them with considerable input from its international staff. In particular, international research staff spend time helping the awardees to develop ideas into instructive case studies, and work with the awardees in reflecting on their experiences. Since the recipients are field practitioners and rarely have a research background, IIMI scientists provide them with assistance in analysis and presentation. Editorial staff help to develop the awardees' skills in the writing and production of the case studies. Computing support is also provided.

The literature on adult learning reflects a general agreement that adults learn from their own experiences. Consequently, they tend to place great value on assistance from others when this facilitates their understanding and provides them with opportunities for new insights.

IIMI's Special Awards Program is designed and implemented to provide learning opportunities to the awardees. They are invited and assisted to:

- Review their concrete experience.
- Develop a reflective observation through analyzing the experience, probing the issues and problems, and postulating causes.
- Develop an abstract conceptualization by verbalizing concepts and principles while developing a generalized framework for tackling the issues and problems.
- Improve their future professional practice, by applying the insights gained through analyzing and presenting the case study.

The approaches applied in the Special Awards Program are firmly rooted in accepted adult learning processes, and aim to provide awardees with a vital resource for their self-development.

MANAGING THE SPECIAL AWARDS PROGRAM AT IIMI

The Institute's Training Unit coordinates and supervises the administration of the Special Awards Program in consultation with IIMI staff involved in providing support to the award recipients. Draft administrative proce-

dures for the program have been presented to IIMI's international staff for analysis and comment. IIMI's Management Committee discusses and approves them after revision by the Training Unit to incorporate suggestions from IIMI staff. The procedures aim to establish criteria of application, selection and the placement of awardees, and to emphasize the necessary steps for program planning (orientation), implementation (supervision) and evaluation, including follow-up and post-evaluation phases.

PROGRAM PUBLICITY

The Institute publicizes the awards through various media, including newsletters and irrigation-related publications, and by notifying irrigation institutions about the availability of awards.

APPLICATION AND SELECTION

Applications are sent either to IIMI's field offices or to headquarters, and they include a summary of the experience the applicant proposes to write up under the special award. The candidates that IIMI attract to this program are professionals who typically work in irrigation, agriculture or other relevant departments within national agencies, and who have had considerable field experience in enhancing system performance. Awards are granted on the basis of the following criteria:

- Demonstrated professional competence.
- Experience in planning and implementing innovative system management approaches.
- Presentation of a valid proposal describing the expected results of the study in terms of improved irrigation management practices.
- Potential for publishing an instructive case study.
- Interest of an IIMI staff member to offer substantive assistance in writing the case study.
- Willingness to participate in IIMI's training program when necessary.

A Selection Advisory Group comprising a Training Specialist and international staff at headquarters and at field offices is established to review applications The final selection of awardees and decisions on their placements are made by the Training Unit after consultation with this group. The selection is presented to IIMI's Management Committee in the form of clear recommendations for its approval.

OUTPUTS OF THE SPECIAL AWARDS PROGRAM

The main output of the Special Awards Program is published case studies documenting the innovative management practices implemented by the awardees. These studies are distributed to a wide audience, including dissemination through seminars and workshops, and are also used to develop training materials.

Through the case studies, innovations developed in real situations by irrigation professionals are made accessible to other managers and researchers concerned with irrigation management, enabling their insights and approaches to be shared within the international community of irrigation professionals. The awardees are also invited to participate in IIMI's training programs as trainers, to share, analyze and discuss their case studies, giving concrete examples and details of problems faced and solutions attempted.

EVALUATION OF THE SPECIAL AWARDS PROGRAM

IIMI is developing a procedure for ongoing evaluation while the awardees are writing the case studies, as well as a post-evaluation exercise, in order to provide feedback and to assess the effectiveness of the Special Awards Program. The training staff contacts irrigation institutions to ascertain the use and influence of the studies in changing procedures and management behavior. Training agencies are also asked to evaluate the usefulness of the case studies as training materials. The effectiveness of individual awardees is assessed through their participation as trainers in IIMI's training programs.

Based upon the results of this assessment, IIMI reviews and improves the implementation of the program, particularly with respect to illustrating management innovations and the professional development of the awardees.

PART 2

Reinforcing Management at System Level

CHAPTER 4

A Comparative Study of Farmer-Managed Systems in Northern Pakistan

Jacob W. Kijne

INTRODUCTION

IN 1986, A World Bank evaluation mission recommended that the Aga Khan Rural Support Programme (AKRSP) should study the potential for distributing available water more efficiently throughout the new small-scale irrigation systems that have been developed with AKRSP assistance throughout the Northern Areas of Pakistan. The mission also urged that Northern Area farmers be assisted in adopting methods to minimize water losses and system maintenance requirements. Subsequently, IIMI Pakistan was asked by AKRSP to carry out research on these issues, with the overall objective of determining the actual performance parameters of such newly established farmer-managed irrigation systems (FMIS). In collaboration with AKRSP, and supported by funding from the Aga Khan Foundation (AKF), IIMI Pakistan implemented a six-month comparative study of a small number of farmer-managed irrigation systems in the Gojal region of Hunza, Gilgit District, Northern Areas. This paper reviews the principal findings of the study, a preliminary report of which was submitted to AKF, Pakistan, on 1 September, 1989.

OBJECTIVES AND DESIGN

The primary objective of this research project was to determine a range of irrigation efficiencies of small-scale mountain irrigation systems in northern Pakistan. Reliable data on actual physical performance parameters of such systems were virtually absent, and this research sought to provide significant knowledge about an irrigation system commanding some 400,000 ha of the national irrigation environment.

IIMI was also interested in initiating studies of FMIS in Pakistan to expand the geographical scope of its management research activities focusing on the special problems of delivering support services to the farmer-managed sector. Data and information on the performance of small-scale irrigation systems in northern Pakistan would facilitate comparative analyses of similar systems elsewhere in the trans-Himalaya region including Nepal, where IIMI research on FMIS has already resulted in significant changes in national irrigation policy and programs.

A secondary objective of the project was to determine the suitability of well-established, practical field research techniques and methodologies for measuring the actual physical performance of small-scale irrigation systems in mountain environments, where conditions of climate, soils, slope and aspect are highly variable and often extreme. No new technologies were developed or tested.

While developing the research design, it was recognized that there were two broad categories of small-scale irrigation systems in the Karakorum Mountains of northern Pakistan: (1) long-established systems which could be assumed to be essentially stable or mature, and (2) systems newly constructed or expanded in the past 5 years, with AKRSP assistance, which were in the process of stabilizing. It was initially thought that it would be necessary to carry out comparative analyses of a sample of paired systems from each category if the key issues of concern to AKRSP — opportunities for enhancing water distribution efficiency, water loss minimization, and improved system maintenance processes — were to be effectively examined in newly established or improved FMIS.

Limited resources and time, however, restricted the research to a single, relatively accessible area of Gilgit District. Following a rapid field reconnaissance in Hunza-Gojal, six small-scale irrigation systems were selected for study. In each of the three Gojal villages, one AKRSP-assisted system was paired with an older, well-established FMIS.[20] Following initial field surveying and mapping, the irrigation operations (water conveyance, distribution and field application) and maintenance activities were systematically observed and measured in each of the six systems. The data obtained form the primary basis for the research results are reported here.

Finally, it should be noted that although the narrow focus of this research was on efficiency irrigation issues, it is understood and acknowledged that FMIS frequently have multiple objectives. Their logic, therefore, may or may not emphasize the efficient use of water in strict engineering terms, and an evaluation of their operational performance solely by such strict criteria may well be both inappropriate and undesirable. Nevertheless, as Coward and Levine (1989) have pointed out, much recent research on FMIS has been so heavily social science-oriented that the equally important engineering dimensions of FMIS have been under-emphasized. This research makes a modest effort to redress that imbalance. It also represents only an initial component in a larger effort to compare FMIS performance over both physical and social parameters for a wider area of northern Pakistan.

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[20] Field observations and measurements for each system were done over a 5-month period by a team comprising two IIMI Pakistan field professionals (an irrigation engineer and a hydrologist), two IIMI Pakistan junior research associates (both engineers) and two AKRSP engineers, under the general guidance and supervision of two IIMI Pakistan international staff. In the course of the study, advice was obtained from the Soil Survey Institute of Pakistan. Soil samples were analyzed by the Soil Fertility Survey and Soil Testing Institute, Punjab, and the soils laboratory of the Center of Excellence in Water Resources Engineering, Lahore.

PROJECT AREA

Physical Environment

The Karakoram region of northern Pakistan falls under a partial rain shadow and does not receive the monsoon rains. Summer storms occasionally visit the area, but in general it is arid (annual rainfall is about 125 mm) and agriculture depends on irrigation. (This is distinctly different from much of Nepal Himalaya where FMIS studied were in areas which receive heavy monsoon rains [up to 2,000 mm] and rice is grown.) In most cases, irrigation channels are fed by glacial sources and snow melt. The irrigation systems are small-scale, traditionally farmer-designed, constructed and managed using indigenous technology and techniques. Glacial melt is tapped and carried as far as 10 km through old channels or recently constructed ones, across precarious slopes to alluvial fans and river terraces which constitute most of the arable land. Where channels cross almost vertical rock faces, a passage is carved out or blasted along the rock wall. In Hunza, channels often take the temporary form of tunnels when they traverse scree slopes.

The local climate in Hunza-Gojal varies considerably with altitude, aspect and slope, and with shading caused by surrounding mountains. These same effects govern the rate of snow and glacial melt and therefore discharges of the mountain streams, which are highly variable and differ on cloudy and clear days during the growing season. Low humidity and intense solar radiation are augmented by strong winds, creating a desiccating environment for crop production. Reliable data on potential evapotranspiration are few (e.g., Butz and Hewitt 1985). Evidence of wind erosion is clearly visible and removal of seeds by the wind has been reported in the area.

Agriculture

The Gojal region comprises the upper portion of the Hunza River valley beginning about 2,500 m above sea level. It is predominantly a single crop area where all annual crops are spring sown and experience a relatively short growing season. The rate of ripening is strongly influenced by temperatures and cloudiness at the end of the season. Close to the border with Hunza proper, the growing period is slightly longer and both sowing and harvesting dates are somewhat more flexible. Crops grown for both market and household consumption include wheat, barley, potatoes and pulses; fodder, vegetables and fruit are primarily produced for local consumption. Each village also has a sizeable area of adjacent irrigated "waste" land which is usually divided among resident households and is used for the production of firewood (e.g., Hippophae sp., Salix and Poplar) as well as for grazing and fodder for livestock, especially during the winter months.

Soils

The soils in Hunza-Gojal are immature soils. The parent material in the valley floor is present as river terraces, alluvial fans, glacial moraines or mud flows. Soil formation is largely due to the deposition of silt carried by the irrigation water. The top soil is enriched gradually with these fine materials, and the water holding capacity of the top few inches of the profile improves, whilst leaving the subsoil unchanged. Some scree have well graded young soils which are cultivated, if the slope permits, with alfalfa and forage trees.

The agricultural soils are characterized by shallow profiles (maximum of 0.6 m), by low water holding capacity (at most, 12 percent volume, which is often reduced further by the presence of rocks and boulders buried in the soil), by low inherent fertility and by alkalinity (pH in excess of 7.8). Again, this is different from Nepal, where the soils of the study areas contain mainly clay and silt, and are found on well-drained, deep river terraces. Soils here, however, show a large degree of spatial variability, due in part to differences in parent material over short distances. Inherent variability in soil depth has been enhanced by the formation of horizontal terraces on a naturally sloping terrain.

Compaction and crust formation are common, caused by free wandering of livestock after harvest and — during early irrigations — by the farmers walking through fields, or directly by the flow of water, weeding and thinning.

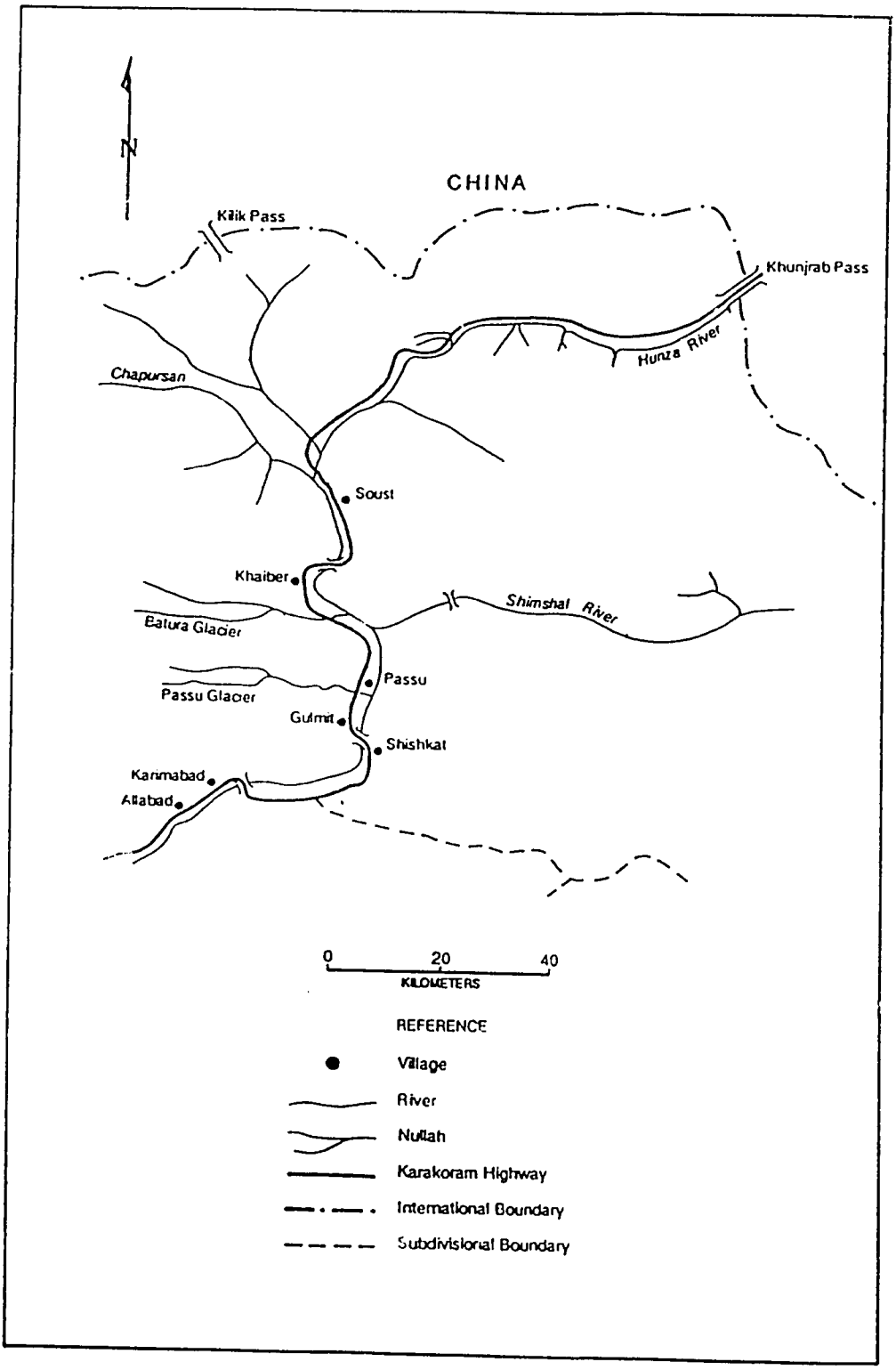
In most of the villages of Gojal, plowing is done by tractors, except on inaccessible steep and terraced fields where it is done by the traditional plow, pulled by a bullock. These plows penetrate no deeper than 15 cm and do not turn the soil over, and therefore, farm-yard manure applied is not buried properly. In one of the sample areas, the new Khaiber area (Figure 4.1), cultivation is done by hand tools, since the suspension bridge cannot be crossed by bullocks or tractors.

Availability of Labor

Shortage of farm labor is one of the major factors affecting crop husbandry in both old and newly developed areas of Gojal. The majority of the young men are working outside the area. The growing season coincides with the tourist season, and in the more "touristic" villages (e.g., Passu) young farmers work as porters or guides and some run their own inns and hotels. To relate the labor shortage to the tourist industry may not be valid for the whole of Hunza-Gojal, but summer is also the season for building houses and repairing animal sheds and houses. Some people accompany livestock to the summer pastures.

Often, women irrigate the fields but they have to do so between household chores and while attending to the needs of their children. Moreover, the tasks of growing vegetables and collecting firewood also fall to the women. It is hardly surprising, therefore, that irrigation in the older areas near the villages is often done with a minimum of physical attendance in the fields. This is not the case in the newly developed areas, which are far away from the villages and where irrigation is not so easily interrupted by other activities.

Figure 4.1. Map of Hunza-Gojal, Gilgit District.



Sample Irrigation Systems

Six irrigation channels were selected in Hunza-Gojal for a detailed study of operation and maintenance. Three of these are old channels and three are newly constructed with AKRSP support. The selected systems are located in the villages of Passu, Khaiber, and Soust (Figure 4.1). Each of these villages has an old and a new irrigation system.

In general, three types of channels can be distinguished in each system: the approach channel, supply channel, and the distribution channels. The first two, approach and supply channels, constitute the conveyance part of the irrigation system but not all systems have both types of channels. The approach channel is defined as that part of the channel which lies between the intake and the last regulator or escape structure through which water can be made to escape back to the mountain stream *(nullah)* from which the water has been diverted. The supply channel has no escapes and conveys the water from the approach channel to the network of distribution channels. Data on lengths and slopes of the different sections of the systems are listed in Table 4.1.

Table 4.1. Systems characteristics.

	Old systems			New systems		
	Passu	Khaiber	Soust	Passu	Haiber	Soust
Irrigated area (ha)	14.5	18	16	14	12	17.5
Maximum Q, (1/sec)	85	145	170	170	115	85
Approach channel: length (m)	600	300	120		800	
Slope	0.014	0.025			0.004	
Supply channel: length (m)		250	90	3900	2100	950
slope		0.014	0.01	0.002	0.004	0.001
Distribution channel: length (m)	4600	1200	650	2600	650	1800
slope	0.004	0.053	0.06	0.011	0.001	0.009-0.030

In all sample systems, the intake structure consists of some type of diverting wall built in the nullah from readily available stone and rock (or in the case of the new system in Khaiber, built in the Hunza River itself). Sometimes there are two diverting walls and two intakes, one each for low and high discharges in the mountain stream. It is usually necessary to rebuild the structure each spring, as it is washed away during

high floods each year. Flow regulation takes place by moving rocks in the nullah near the intake and/or by regulation of the escapes along the approach channel.

The bed material of the approach and supply channels consists of rock and stones in the old systems, and of silt in the new systems. The silt has been deposited in a relatively short time due to the much smaller slopes of the channels in the new systems (Table 4.1).

Water shortages exist in both systems in Soust during early spring, and also later in the season depending on the weather. The channels in Soust take water from a nullah that is fed by snow melt. The rate of snow melt is highly affected by temperature and cloud cover. This has necessitated the introduction of a rotation between two channels that obtain their water from the same nullah, one feeding the old system in Soust and the other the old system in Nazimabad, on the left bank of the nullah. The new system in Soust is initially excluded from the rotation because farmers prefer to start with their fields near the village (Old Soust); farming begins later in New Soust. However, once fields have been prepared there, the new channel receives water continuously. Rotations between fields take place throughout the season in both New and Old Soust and also during early spring in Old Khaiber.

A night reservoir is operated in the old system in Soust, but only during April and May. Up to six farmers can be supplied with water stored during the previous night; it has a capacity of about 340 cu.m.

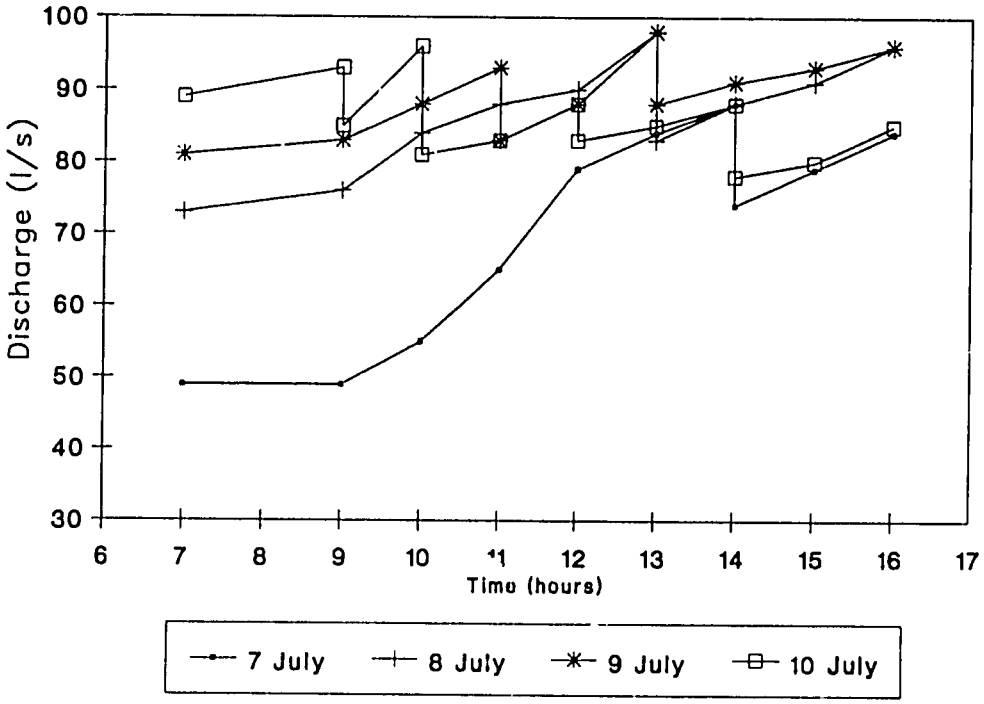
In the old system in Khaiber and the new system in Passu, *chowkidars* (watchmen) are employed. In Khaiber the chowkidar is appointed by a sub-village and he patrols the channel, carries out repairs, cleans the desiltation tank, regulates the flow at the intake, opens the channel at 4 a.m. and closes it at 5 p.m.

Four chowkidars are employed in the New Passu system. They regulate the flow at the intake and patrol the channel four or five times a day. The effect of regulation can be seen in Figure 4.2, where the discharge at the intake of the channel of New Passu during the day has been plotted for a number of sunny days in July. Only by regulation can the flow be maintained at a near steady and safe level throughout the day, paying due consideration to the stability of the channel embankments. Other tasks of the chowkidars include the irrigation of forested areas, usually at night, and some maintenance.

In addition to irrigation, the water in the old systems is also used for domestic purposes and sometimes for the running of flour mills. Another important use of irrigation water in the new systems at Khaiber and Soust is in soil formation by ponding the water and depositing the silt load in shallow recessions.

The old channels are quite stable, in spite of their steep slopes, and require little maintenance. Numerous rocks and boulders act as natural drop structures. Maintenance of the distribution system is left to the individual farmer.

Figure 4.2. Flow regulation at the intake of the new channel at Passu.



Collective maintenance usually takes place in the new systems once a year, at the start of the season. It includes desiltation of the channels and is arranged by the village organization, set up by AKRSP, which also organizes emergency maintenance when required. All farmers are expected to participate or compensate in kind or pay a fine.

METHODOLOGY

Conveyance Losses

Conveyance efficiency has been defined as the flow delivered at a point downstream as a percentage of the flow at an upstream location. Operational losses should not occur between the two measuring points and the observed decrease in discharge between the two points can then be ascribed to percolation and seepage losses.

In the systems studied, it was not always possible to decide whether or not losses due to overtopping and leakage were intentional (sanctioned or tolerated), as the water would often serve some purpose in the irrigation of trees or grasses. The

terminology as proposed by Bos and Nugteren (1974) for the determination of efficiencies in different sections of irrigation systems therefore cannot strictly be applied to the systems in Hunza.

To account for small outflows occurring in the section over which the conveyance losses are to be determined, conveyance efficiency has been calculated according to:

$$E_c = \frac{Q_2 + \left[\frac{d_1}{d_1 + d_2}\right] Q_{out}}{Q_1 - \left[\frac{d_2}{d_1 + d_2}\right] Q_{out}} .100 \qquad (1)$$

where Ec is the efficiency in percent, Q_1 the measured discharge at the upstream location, Q_2 the measured discharge at the downstream location, Q_{out} the measured or estimated (small) outflow between the measuring points, d_1 and d_2 the distances to point 1 and point 2, respectively. A similar approach could be followed for a small accidental inflow within the measuring reach.

The distance between the measuring points was made as long as possible to improve the reliability of the observed difference between the two measured discharges and to obtain a representative figure.

No conveyance losses were determined in the approach channels, as losses occurring in these sections are part of flow regulation. For Old Passu, no conveyance efficiency could be calculated, as there is no supply channel (Table 4.1).

Distribution efficiency was calculated using an equation similar to (1), taking measuring points in the distribution channels. All flow measurements were carried out by the velocity-area method, in which the velocity was determined with a small current meter. It can be assumed that seepage losses[21] from conveyance channels are linearly related to discharge, according to the following relationship:

$$q = k.Q \qquad (2)$$

where Q is equal to the discharge in the channel, q the rate of change of Q with distance along the channel (-dQ/dx) and k is a seepage factor. This assumption is at best an approximation, as has been shown by Wachyan and Rushton (1987), but it permits easy comparison of losses between different channels through comparison of their k-values.

The coefficient k can be calculated by integrating (2) between the limits of Q1 and Q2, which are measured at the two ends of the reach, a distance X apart, as follows:

$$k = - (1/X).(\ln Q2/Q1) \qquad (3)$$

Conveyance losses per unit length of channel per unit cross section are found by dividing the product of k and Q by a characteristic value of the wetted perimeter. Changing the time units from seconds, as in the values of Q, to days gives the losses

[21] This, of course, is not true for "intentional" losses such as overtopping.

in units of m per day as is commonly done (e.g., see Lauritzen and Terrell,1967), thereby inferring that the losses are a function of the wetted perimeter of the canal.

Application Losses

Application efficiency is a sensitive measure of the degree to which water that has been applied to the field becomes beneficial to crop growth by being stored in the rootzone for uptake by plant roots. Application efficiency can be expressed as the ratio of the amount of water stored in the rootzone and the amount applied to the field:

$$Ea = 100 \frac{D.(FC - PWP).(1 - PAW/100)}{V/A} \qquad (4)$$

where Ea is the application efficiency in percent, D the depth of rootzone, FC is field capacity (moisture content reached presumably a few days after irrigation), PWP is permanent wilting point (moisture content in the soil when plants wilt permanently, presumably the lower limit of the storage capacity of soil for water), PAW is the percentage of actually available water in the soil, and V is the volume of water applied to a field of size A.

This concept of efficiency is based on the assumption that free drainage occurs and that whatever water is applied to the soil that cannot be stored in the rootzone, drains out of the profile. The amount of water in the rootzone cannot therefore be more than what is in agreement with field capacity for any length of time, and whatever is stored is available for evapotranspiration. This concept has been severely criticized in recent years (e.g., Hanks and Ashcroft 1980) but is still useful as a basis for efficiency determinations at field level.

An alternative definition of application efficiency relates the depth of water applied to the field with the amount of water used by evapotranspiration during the irrigation interval, as follows:

$$Ea = 100 \frac{Epot.Fc.Fgc.Fae.I}{V/A} \qquad (5)$$

where Epot is the potential evapotranspiration, Fc is a crop coefficient depending on type of crop and period within the growing season, Fgc is a coefficient that depends on ground cover (especially important with crops that do not provide a complete ground cover, e.g., potatoes and tree crops) Fae is a coefficient which expresses the effect of advective energy not accounted for in the Epot term, I is the irrigation interval, and V and A are volume and area as defined before.

In this study, both approaches (equations 4 and 5) have been followed. Sample fields with wheat, barley and potatoes were selected, as far as possible, in the head, middle and tail reaches of distribution channels in the irrigation systems studied. In New Khaiber, agricultural production has hardly started yet, so sample fields with these three crops could not be found for all systems.

Depth of soil profile was determined by augering. Soil samples were analyzed in the laboratories of the Soil Fertility Survey and Soil Testing Institute and the Centre of Excellence of Research in Water Resources, both at Lahore. From these analyses an (incomplete) characterization of the soils was obtained, which allowed an estimate of the values of FC and PWP to be made. Moisture contents in the soil profile were assessed by the USDA field method, in which the interval of 25 percent available moisture were divided into two intervals of 12.5 percent.

The depth of the rootzone was determined by removing a few wheat or barley plants, or by opening up a ridge in case of potatoes. A reasonable estimate of the effective root depth could thus be made, and the values obtained were checked against values reported in the literature (FAO Irrigation and Drainage Papers 24, 33 and 36).

The discharge in field channels was usually measured with a RBC-flume (with a capacity of 8.8 l/s) and in some cases by floats. Frequent measurements were required when the discharge in the distribution channel varied during the course of an irrigation that was being monitored.

Infiltration opportunity times, i.e., the time lapse between initial wetting and the disappearance of water from the surface, were measured at sites marked with stakes in the field or in segments of zig-zag furrows in the case of potatoes. In mature grain fields, where it was impossible to place the stakes, infiltration opportunity times were recorded for patches in the field which could be identified by different means.

The degree of leveling of the field was recorded on a scale from 1 to 5. The irrigator's presence was similarly recorded, as was his or her intervention in the process of irrigation. Irrigation intervals were ascertained from farmer interviews and field observations.

Potential evapotranspiration rates were derived from (limited) values in the literature (Butz and Hewitt, 1985), combined with values from evaporation pans placed at New Passu and Old Sousl to which a conversion factor was applied. Values of the crop coefficient, the ground cover coefficient and the advective energy factor were estimated from literature sources (FAO Handbooks referred to above) and through "common sense."

The method of propagation of errors has been used to try to determine which of the two approaches for calculating the application efficiency is likely to be more reliable under the circumstances of the field work in Hunza-Gojal. However, the available data are insufficient for a rigorous statistical analysis that would have provided a sound basis for choice.

It was concluded that both methods have their merits, depending on the circumstances. For example, early in the season the efficiencies obtained from equation (4) may be more reliable than those from (5).

FINDINGS

The number of irrigations and the total amount of irrigation water applied during the measuring period are listed in Table 4.2 for wheat, barley and potatoes. The average soil depth is presented in the same table. Soils are shallow, and many small irrigations

are given. The average number of irrigations is the same for grains and potatoes, but the average amount applied per irrigation turn is significantly less for the potato fields. There are no significant differences, in number of irrigations and amounts applied, between old and new schemes.

Values of the seepage factor k and of conveyance efficiencies for supply and distribution channels are listed in Table 4.3. Variability amongst the measurements is high, probably resulting from the difficulty of measuring flow velocities in fast flowing channels with a current meter. Statistically, therefore, only the low value of k for conveyance losses in the New Passu channel differs significantly from the other values. Losses in distribution channels exceed those in supply channels.

Table 4.2. Average values of irrigation parameters.

		Wheat and Barley			Potatoes		
	Soil depth (cm)	Number of turns	Depth applied (cm)	Total application (cm)	Number of turns	Depth applied (cm)	Total application (cm)
Old							
Passu	48	14	5.8	81	13	2.5	33
Khaiber	25	16	6.1	98	12	3.3	40
Soust	61	14	7.1	99	14	2.3	32
Average	45	15	6.3	95	13	2.7	35
New							
Passu	10	19	4.6	87	24	1.8	43
Khaiber	23						
Soust	18	16	4.3	69	15	5.1	77
Average	17	18	4.5	81	20	3.1	62
Average of all	31	16	5.5	88	16	2.9	46

In Table 4.4, the average values of application efficiencies and other parameters are listed for wheat and barley fields. The Epaw values refer to efficiency values calculated from the amounts of water stored in the rootzone (equation 4) and Ecu values were calculated from evapotranspiration data (equation 5). These two sets of data differ by an order of magnitude. The nonuniformity values are equal to the relative standard deviations of the infiltration opportunity times (i.e., their standard deviation divided by the mean value).

Differences between the mean values for old and new systems are significant for the length of the fields, flow at field inlets, degree of farmer intervention and available water in the rootzone at the time of irrigation.

A similar set of data is also included in Table 4.4 for potato fields. Here, the mean values for old and new systems do not differ significantly.

Table 4.3. Seepage factor, k of conveyance and distribution channels (mean values per system).

Conveyance units (x 0.0001 m^{-1})		Distribution units (x 0.0001 $^{-1}$)
Old		
Passu		5.8
Khaiber	2.8	
Soust		5.8
New		
Passu	0.4	1.7
Khaiber	0.9	
Soust	5.3	5.5
Mean Value	2.6	4.5

Table 4.4. Average values of application efficiencies and other parameters.

	Wheat and Barley			Potatoes		
	Old	New	All	Old	New	All
Epaw (%)	7	15	11	12	8	10
Ecu (%)	54	71	63	54	45	50
Non-uniformity	44	44	44	43	46	44
Length (m)	25	14	20	34	61	44
Flow (1/sec)	7.5	4.2	5.7	2.5	3.3	2.8
Farmer intervention	2.5	3.6	3.1	3.6	2.4	3.1
PAW at irrigation (%)	70	38	54	51	47	50

Notes: Ecu is application efficiency from (5)
Length is length of field or furrow
Flow is flow at field inlet
PAW is percent available water in rootzone at time of irrigation

DISCUSSION

The amount of water applied to potato fields (average value of 46 cm during the measuring period, Table 4.2) seems low compared with an expected seasonal crop water requirement of some 50 cm. Potatoes were planted around the middle of May and harvest was expected to take place around 15 September. At the end of the measuring period, 1 August, some five more weeks of irrigation were to follow, which means an additional 30 cm of irrigation, given an average irrigation interval of 4 days (the most common value) and an average application of 2.9 cm. Nevertheless, 76 cm seasonal application and average application efficiency for potato fields of 54 percent (Ecu value in Table 4.4), give a consumptive use of only 41 cm.

No such discrepancy exists with the wheat and barley data. The grains were sown earlier and were closer to harvest at the end of the measuring period. Moreover, an average of 88 cm of water had already been applied. With an expected seasonal irrigation requirement of about 55 cm, and application efficiency of 63 percent (Ecu value in Table 4.4), the seasonal requirement had been already applied.

From these comments it is also apparent that the Ecu values are more likely to be of the correct order of magnitude than are the Epaw values in Table 4.4. It has been observed in the field that the soil profiles are shallow (Table 4.2) and the rootzone is often underlain by an impermeable layer of rocks and pebbles. Under these circumstances, the assumptions inherent in the derivation of equation 4 do not apply: free drainage from the rootzone is obstructed, and water applied to the soil in excess of field capacity remains available for uptake by roots during the irrigation interval. Application efficiencies that have been calculated assuming that water is only available between field capacity and permanent wilting point clearly underestimate the real uptake of water by plant roots.

Differences in irrigation practice between old and new systems are significant in wheat and barley fields, but not in potato fields. The lengths of the fields, the flow at field inlets and the amount of water present in the soil profile at time of irrigation were all lower for grain fields in the new systems than in the old systems. One would expect that these factors combined with a higher degree of farmer intervention, would lead to higher values of application efficiencies in the new systems. The average values of both efficiency parameters clearly show this difference, but because of the high standard deviations of the efficiency values, these differences are not statistically significant.

The dependence of application efficiency (Ecu) on the other parameters listed in Table 4.4, has been investigated.

Figure 4.3 shows the relation between efficiency and the flow at field inlet for potato fields. Efficiency clearly decreases with an increase in discharge available to the farmer at his field inlet. It should be noted that the largest flow is only 5.6 l/s. The correlation between the two parameters of Figure 4.3 is significant at a 0.01 probability level. A similar decrease in efficiency with flow at the field inlet is apparent in grain fields.

In Figure 4.4, efficiency is plotted against degree of farmer intervention for all wheat and barley fields. It is interesting to observe that high efficiencies are possible regardless of the degree of farmer intervention. There appears to be an indication that farmer's intervention in irrigation has an optimum. The same tendency exists when efficiency data are plotted against farmer intervention for potato fields. For smaller sets of data, a clear improvement in efficiency may be found with an increase in farmer intervention (Figure 4.5, for potatoes in the new areas).

An increase in nonuniformity, i.e., the variability in infiltration opportunity times in the field, is expected to lead to a decrease in application efficiency. This has been observed, and it is particularly apparent when the PAW-efficiency is plotted as dependent variable, as in Figure 4.6. Low efficiencies may occur at low values of nonuniformity — obviously resulting from other effects — but high efficiency does not occur when the nonuniformity is high. This points to the importance of the leveling of fields to attain more uniform application of water.

Figure 4.3. Application efficiency (%) as function of flow at field inlet for potato fields.

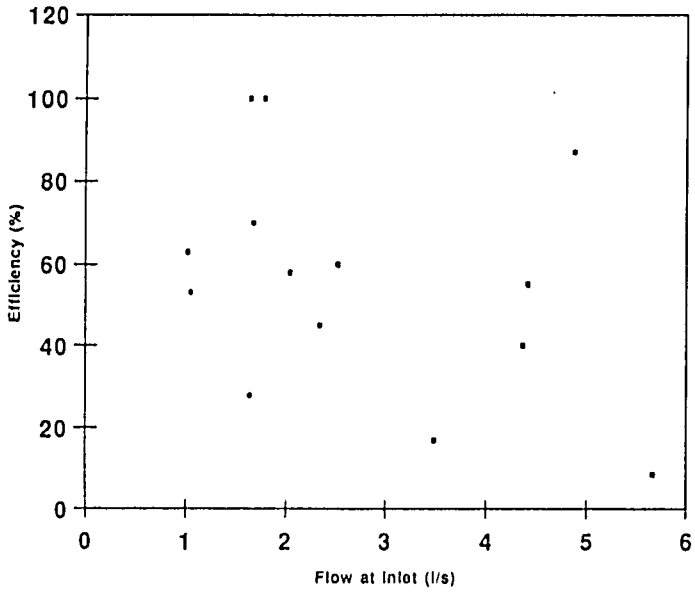


Figure 4.4. Application efficiency (%) as a function of degree of farmer intervention for all wheat and barley fields.

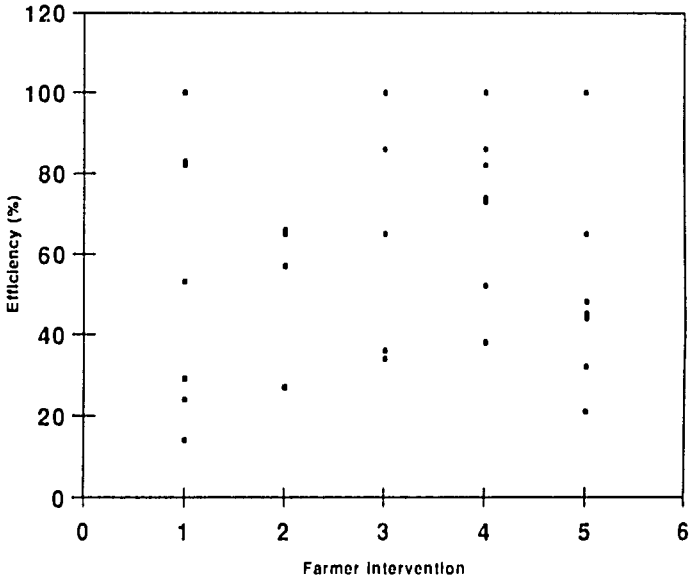


Figure 4.5. Application efficiency (%) as a function of farmer intervention for potato fields in the new systems.

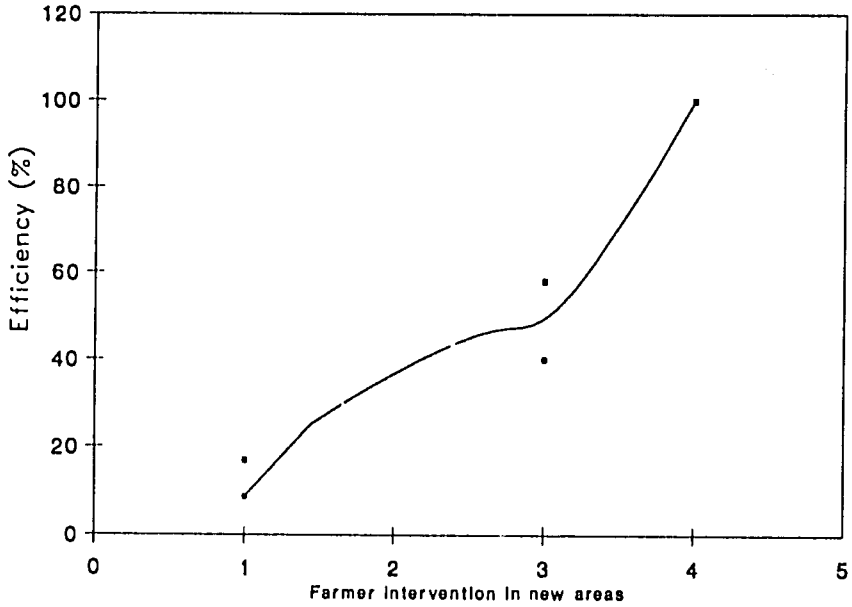
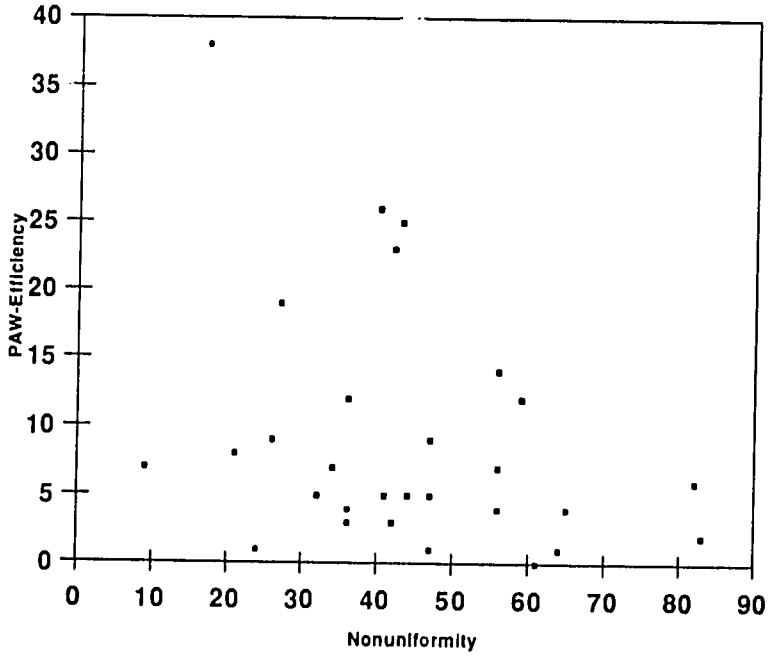


Figure 4.6. Application efficiency (%) as a function of nonuniformity for all wheat and barley fields.



Conveyance efficiencies are listed in Table 4.3. It is not meaningful to calculate distribution efficiencies for the network of distribution channels unless the total length of distribution channels flowing at any time is taken into consideration. When conveyance losses are expressed as seepage loss per unit area, a value of about 0.2 m/day is obtained for the supply channel in New Passu; the other channels have a loss of about 1 m/day. These values are in reasonable agreement with data reported in the literature. For example, Wachyan and Rushton, 1987, gave values for unlined large distributaries in southern India of about 0.2 m/day. Values of 0.45-0.6 m/day for pervious soils and of 0.75-1 m/day for gravel have been reported (Worstell 1976). Most of the conveyance channels in the sample systems traverse gravel, whereas the supply channel of New Passu is well-sealed because of silt deposits.

CONCLUSIONS AND RECOMMENDATIONS

The large variations in present application efficiencies indicate that improvements could be made. One expects that a more precise control of water at the field inlet, better leveling of the fields, and appropriate intervention by the irrigator during the process of irrigation would lead to improved efficiencies at field level. The data indicate that field losses are less in the new areas than in the old ones, pointing to the importance of the farmer's presence during irrigation and his or her intervention in it.

It is tempting to suggest that less frequent irrigation with larger applications would improve field application efficiency *and* reduce the labor requirement. However, before making that suggestion, one needs to be sure that it can be implemented on the shallow soils of Hunza-Gojal.

Water scarcity does not affect system operation in Gojal to a large extent. Only during the first few weeks of the season are strict rotational rules implemented in some of the systems. In the new irrigation systems, however, water scarcity could occur, at some point, with further land development.

Operation and maintenance of the systems is done either by the farmers themselves on an informal basis, as in the old systems, or by chowkidars, employed specifically for that purpose. Whether chowkidars are employed depends on circumstances. In New Khaiber, where the farmers walk along the conveyance channel to get to their fields, chowkidars were no longer needed once land was subdivided into individual holdings. But in New Passu, where the supply channel is on one side of the road and the fields are on the other, chowkidars are employed to adjust flows, to patrol and inspect the supply and approach channels, and to do minor maintenance. Old systems have a lower demand for maintenance; in the new systems, maintenance of approach and supply channels is done once a year, organized by the chairman of the village organization who also arranges for emergency maintenance to be carried out when necessary.

In both new and old systems it often appears that water is being wasted, but when it is actually irrigating grasses, bushes and trees on so-called waste land it is well-spent, because it helps to provide fodder for animals and firewood for the households.

Drainage water ponded in low depressions leads to soil improvement by silt deposition.

Conveyance losses in supply and distribution channels are much as expected, given the types of soil they traverse. These losses are no larger in the new channels than in the older ones, undoubtedly because of the sealing of channel beds by silt deposition, facilitated by the relatively flat slopes of the new channels. In the New Passu channel the losses are even less than in the older channels.

It was found that it took more time than was anticipated to supervise an activity of this nature in such a remote area as the Northern Areas of Pakistan. First, because of frequent cancellations of flights between Islamabad and Gilgit on account of adverse weather conditions, all but one of the trips to Hunza-Gojal had to be made by road. The trip between Islamabad and Gulmit, where the field staff had its quarters, took between 16 and 25 hours each way, depending on the road conditions. Second, the field team required considerable supervision because team members were unfamiliar with the environmental conditions of Hunza-Gojal in general, and of the irrigation systems in particular.

The obvious lesson in this is that travel time and supervisory time should be budgeted realistically for projects carried out far from IIMI-Pakistan's headquarters in Lahore.

RELEVANCE FOR IIMI AND NEXT STEPS

Among the several research themes emphasized in IIMI's current strategy is the management of irrigation support services to farmers focusing on the special problems of improving agency effectiveness in delivering assistance to farmer-managed irrigation systems, in order to enhance both the productivity and sustainability of these systems.

Most immediately, it is possible to communicate some of the foregoing recommendations (e.g., improved field leveling to increase irrigation application efficiency, optimal length of furrows for irrigating potatoes) to existing agricultural extension services in Gilgit District. Less certain is the degree to which these recommendations would be further disseminated to farmers in ways that would lead to their adoption.

Clearly, the research on FMIS in Hunza-Gojal has yet to determine all the causative factors that influence the overall performance of small-scale irrigation systems in northern Pakistan. However, significant progress has been made in defining a range of physical performance parameters. A deeper analysis of the data presented here, in conjunction with research findings on FMIS in analogous environments elsewhere and including the social dimension, may permit the synthesis of a general conception of irrigation management in harsh mountain regions which could yield "first approximation" answers to that important issue.

The results of such an integrated effort should be disseminated to AKRSP, which has developed a successful intervention strategy for assisting FMIS development and improvement (e.g., Maliha Hussein, et al. 1989), as part of a larger institutional development program seeking to achieve a more self-sustaining and productive rural

economy in northern Pakistan. The capacity of AKRSP and constituent village organizations to apply those results could be enhanced by further training of local engineers and social organizers to conduct comparative, diagnostic and monitoring studies of FMIS performance. The participation of two AKRSP engineers throughout the field phase of this project was a modest first step in that direction.

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CHAPTER 5

Irrigation Management for Crop Diversification: IIMI/IRRI Studies

Senen M. Miranda

INTRODUCTION

IRRIGATION IS NORMALLY seen as a means of reducing risks associated with rainfall variability, extending potential growing seasons, and creating a wider range of cropping and farming choices. The degree to which one or more of the benefits is attained is dependent upon the availability of the basic water supply and the degree of control which can be exercised over its delivery.

Due to government policy initiatives to expand rice production, the primary objective of irrigation projects implemented since the mid-sixties in the humid tropical areas of Asia has been to provide a more reliable supplementary supply of water during the wet season for the cultivation of rice under wetland conditions. Even the reduced water supply during the dry season is used to grow an additional crop of rice on a more limited area. The heavy investment in irrigation has provided the controlled flooded water environment considered necessary to take advantage of the full potential of the new high yielding and early maturing rice varieties. However, the success in rice production which has enabled the attainment of self-sufficiency in a number of countries in Asia has also resulted in a reduction in the economic returns from irrigated rice lands.

Theoretically, there are at least three ways by which this problem could be addressed: by increasing the economic yield of rice, by increasing the area served by scarce water resources through more effective and efficient irrigation system management, and by introducing crops of higher value than rice into the irrigated rice farming systems. The Rockefeller Foundation provided a grant, effective 1 July 1987, to the International Irrigation Management Institute (IIMI) and the International Rice Research Institute (IRRI) for the two international institutes, with their complementary strengths, to conduct a joint study of the three options. IRRI clearly has an interest in the first option. The second is part of IIMI's mandate to improve irrigation system management. Both institutes are concerned with the third option of getting higher economic and more equitable social returns from the water and its associated land. In addressing the three options, the Project attempts to look at the problem from a comprehensive point of view to include agronomic, socioeconomic and institutional issues related to rice and nonrice crops in irrigated rice-based farming systems.

This tri-country collaborative Project has been conducted in Bangladesh, Indonesia, and the Philippines which are all in the humid tropics of Asia. The six broad objectives of the Project are:

- To characterize the factors influencing the options for changes in rice-based farming systems, and to identify the more important options in selected geographic locations.
- To determine the degree to which different levels of irrigation system performance influence the ability to incorporate changes in the farming systems effectively.
- To develop efficient and economical methods for managing irrigation water delivery and the use of post-rice residual water for rice-based systems in which nonrice crops are grown, with special reference to the implications for agronomic practice and for institutional performance and change.
- To transmit and interpret the research findings to agricultural and irrigation system managers, planners, and policymakers to encourage informed and better decision making.
- To enhance the development of trained professionals in the area of irrigation problems through the provision of graduate research opportunities.
- To provide an opportunity for IRRI and IIMI staff to interact in a variety of collaborative activities permitting the development of an effective and mutually supportive long-term relationship.

The initial activities consisted of discussions at IRRI, in April 1987, among scientists and administrators from both institutions. These were followed by consultation meetings in early October 1987 with national agencies in the Philippines and Indonesia. Because of the unstable political situation in Bangladesh, only limited consultation could take place there in late January 1988. In all three countries, scientific staff from IIMI and IRRI met jointly with officers of appropriate national agencies and universities to identify the research areas and strategy for the Project's implementation.

PROJECT IMPLEMENTATION PROCESS

While the broad project objectives were defined early on, the different implementing activities in the identification of problem areas, the selection of research sites, and the various modes of interaction between the two institutes and national agencies had to be done on a country to country basis. The process adopted was guided by the following agreed set of principles:

- Collaborative activity should be concentrated on problems of mutual concern to the two institutions.
- The activity should capitalize on the complementary strengths of the two institutions. These strengths include disciplinary expertise as well as geographical (national) experience, contacts, and logistic capabilities.
- The expected output should be greater and/or "better" than the efforts of the institutions working separately.

- The problems and opportunities addressed should be of significant scope, i.e., the potential practical impact should be large.
- Detailed planning of specific activities should be programmed to permit effective input from staff of the appropriate agencies in the countries in which the work would be carried out.

Setting Country Specific Objectives

Bangladesh

Full details of the Bangladesh component of the IIMI/IRRI collaborative project are covered in the following Chapter 6 ("Studies on Rice-Based Irrigation Systems Management in Bangladesh," Donald E. Parker). Only the work in Indonesia and the Philippines will therefore be discussed in this chapter.

Indonesia

In Indonesia, planning meetings held in June and October of 1987 and March 1988 involved IIMI, IRRI, the Directorate General for Water Resources Development (DGWRD), the Agency for Agricultural Research and Development (AARD) and the University of Gadjah Mada (UGM). The research activities of the Project and the detailed workplan for each of the collaborative institutions were determined during a workshop held at Cirebon, West Java, in June 1988.

The primary objective of the Project in Indonesia is to develop and test irrigation system management strategies that take into account variations in the physical environment, crop management, water availability, and farmers' crop decision making. Current irrigation system management practices, largely based on the *pasten* system or derivatives thereof, already respond to certain aspects of demand and supply but are relatively insensitive to variations in physical conditions. Through the Irrigation Committee, a seasonal cropping plan is drawn up based on previous experience, but it is clear that there are significant deviations from this plan during each season. Biweekly estimates of planted area and average water demand are obtained and compared with estimates of water availability during the same time period. As long as supply exceeds demand, the systems operate largely on a continuous flow basis to all parts of the irrigated area, leaving farmers to make local adjustments where needed. When supplies are inadequate, rotational irrigation is implemented between tertiary blocks along a secondary canal and, under more severe conditions, between secondary canals.

For the irrigation management system to be effective, two different time frames should be taken into account: within season system operation and seasonal planning.

Within Season System Operation: Initially, research was concentrated on responses to existing irrigation management practices before moving on to innovations later in the Project. The following specific objectives were identified:

- To determine optimal rotational irrigation schedules to be adopted when water supplies are inadequate to meet demand through continuous and simultaneous deliveries to all tertiary blocks. The institutional arrangements and supporting information flows required to implement alternative water delivery practices, including modifications to rotational irrigation, will be evaluated.
- To evaluate the relationships between irrigation system operation and groundwater fluctuations that may be detrimental or beneficial to nonrice crops, and to develop methods for the productive use of residual soil moisture and the prevention of overirrigation during periods of abundant water supply that may lead to an untoward buildup of groundwater that may in turn inhibit cultivation of nonrice crops in subsequent seasons.

Annual Planning of Irrigation Schedules: Since the annual Crop Plan involves several components relating to the assessment of water supplies that are based on ten-year moving records — soil and crop water demand, allocation of cropping patterns within the system, and the development of a set of operational plans to accommodate variations in both supply and demand — the following objectives were addressed:

- To develop methods of better assessing water availability, from both rainfall and rivers throughout the year, with particular emphasis on simple methods of predicting the periodicity and intensity of water deficit during the dry season.
- To obtain better estimations of probable cropping decisions made annually by farmers that can be integrated into seasonal cropping plans, to evaluate cropping choices of farmers and assess the constraints on cropping practices or crop establishment, and to develop alternative cropping patterns that better suit variations in physical conditions.
- To improve procedures for dry-season allocation of areas to be irrigated and the crops to be grown, based on predictions of water availability at system level and on assessments of field-level demand.
- To develop plans for operationalizing system management under the Annual Plan and to accommodate anticipated demand and probable water supplies to the system, including assessment of the capability of the system to accommodate alternative rotational irrigation practices.
- To propose modifications of the annual and seasonal planning processes that incorporate more site-specific information including feedback from performance in previous seasons.

The Philippines

In the Philippines, consultation meetings were held in October 1987 with the National Irrigation Administration (NIA), the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD), the University of the

Philippines at Los Banos (UPLB), the Central Luzon State University (CLSU), the Bureau of Soils and Water Management (BSWM), the Bureau of Agricultural Research (BAR) and the Philippine Rice Research Institute (PhilRice). It was decided that IIMI and IRRI, either separately or together, should take major responsibility for developing and facilitating research with collaborating national agencies in the following areas:

- Documentation and analysis of the management procedures of irrigation systems with rice-based cropping (IIMI). The analysis should include an assessment of factors that influence the management and decision-making process of systems managers, central office staff and farmers, as well as policymakers. The analysis should also focus on the changes that may have to be introduced in the systems designed for the monocropping of rice.
- Assessment of the physical characteristics and design of an irrigation system with regard to its suitability for rice-based farming systems, with the possibility of introducing modifications in the present design to support mixed cropping (IIMI/IRRI).
- Exploration of strategies and recommendations for irrigation managers, farmers, and policymakers on how to manage irrigation systems for crop diversification efficiently and effectively (IIMI/IRRI). These include water resource augmentation to extend the dry-season irrigated area in different types of systems, and opportunities for alternative water allocation to establish higher efficiency of water use and greater equity among farmers (rice and nonrice). The results will help to formulate policy recommendations that will support the government's effort in both maintaining self-sufficiency in rice and enhancing farmers' income through crop diversification.
- Identification of the physical infrastructural requirements for effective water control at the farm level to support mixed cropping after wet-season rice and the methods for their optimal use (IRRI).
- Determination and analysis of the factors influencing farmers' decision making in crop selection and management during the dry season within the context of the household socioeconomic situation (IRRI). Factors such as water supply, soil type, farm location, profitability of various crops, availability of off-farm employment, input supply, credit availability, markets, and irrigation service fees for different crops will be investigated.
- Assessment of the status and behavior of dry-season groundwater regimes in nonirrigated areas, particularly in areas adjacent to irrigated rice (IRRI/IIMI). The problems and opportunities that these regimes present for the production of nonrice crops should be evaluated. Soil and crop management and irrigation inputs that can maximize the benefits of both matric and groundwater reserves for nonrice crops should be identified.
- Assessment of drainage options for rice and upland crops under different hydropedological, topographical, and local cropping environments, and their implications for system design and management (IRRI/IIMI). Benefits and costs of investments in drainage facilities should also be addressed.

Research Site Selection

The selection of research sites was greatly influenced by ongoing research conducted by IIMI and/or IRRI in each of the three countries.

In Bangladesh, the research sites chosen initially were the Ganges-Kabodak lift-cum-gravity irrigation system and the North Bangladesh deep tubewells where IRRI has been conducting collaborative research for a number of years with the Bangladesh Water Development Board and the Bangladesh Rice Research Institute. Later, Bangladesh Agricultural Development Corporation deep tubewells in Rajshahi constructed with Grameen Bank participation were added. While the IRRI research has resulted in some significant improvements in the management of irrigation water in the two earlier systems as well as in the crop production practices of farmers, the present Project is conceived to enhance the process of internalizing the available results and to generate relevant new information in support of the Project's objectives.

In Indonesia, two sites were chosen in Cirebon, West Java where IIMI has been conducting research because of their proximity to the Sukamandi Research Institute for Food Crops of AARD. The bulk of the fieldwork is done in the Maneungteung Irrigation System which is a run-of-the river diversion. The second diversion system is at Ciwaringin. Because of its past research activities there, IIMI has established a good database in irrigation management activities at these two sites. Eleven separate studies were conducted in Indonesia.

In the Philippines, the research sites chosen, all in Luzon, are the same systems where IIMI conducted studies on irrigation management for crop diversification with funding from the Asian Development Bank. These are the Upper Talavera River Irrigation System (UTRIS), the Laoag-Vintar River Irrigation System (LVRIS), and the San Fabian River Irrigation System (SFRIS), which are all run-of-the river diversion types. Three other sites are used by IRRI to conduct parallel component studies. Most of the work by both IIMI and IRRI is done in UTRIS where IRRI has had even a longer research presence. Eleven separate studies were conducted in the Philippines.

Professional Development

The Project provided opportunities for graduate research fellowships/scholarships (4-Indonesia, 7-Philippines), attendance in relevant training programs (24-Bangladesh, 3-Indonesia, 19-Philippines), and study tours and conferences for national staff (8-Bangladesh). Active participation in actual research by irrigation, agricultural, and research agency staff has contributed to their gaining on-the-job training experience. One senior staff member in the Philippines and another in Bangladesh were seconded to assist in the day-to-day coordination of the Project and to conduct their own research for their further professional development.

Activities in 1990

With the Project due for completion by the end of 1990, final national workshops were held from 13 to 14 June in Yogyakarta, Java, Indonesia, and from 10 to 12 September in Los Banos, Laguna, in the Philippines, to disseminate and receive feedback on the research findings. In Bangladesh, a workshop scheduled for 23-24 September 1990 could not take place because the necessary government permit was not obtained.

As a final activity, an intercountry workshop was held between 12 and 14 November in Colombo to review and integrate research findings in each country and across the three countries, and to deliberate on the recommended course(s) of future action.

FINDINGS: A SYNTHESIS

The intercountry workshop was able to produce a consensus on an integrated set of findings, recommendations, and the future course of action. These were categorized into: a) Main irrigation system management for rice-based farming systems; b) Farm-level water management for rice-based farming systems, c) Economics and institutional issues in irrigated rice-based farming systems; and d) Critical issues discussed. The following questions were used as a guide in sorting out the findings and recommendations from the Project:

- What are the factors that influence the options for changes in rice-based farming systems?
- What are these options and how do the different factors affect them?
- What are the implications of these changes on irrigation management, at system and farm levels?
- How could these implications be addressed? What recommendations are already utilizable? Is there a need for further research? What should be done next?

Main irrigation system management. Some background issues were considered, such as the differences in the type of irrigation systems used as research sites (large gravity direct diversions in the Philippines and Indonesia, and lift and deep tubewell systems in Bangladesh). It was recognized that there were lessons that could be learned from drier environments (e.g., Egypt, Morocco, Pakistan) where diversification is widespread and where management issues may be simpler or better understood. It was also recognized that the main issue is the irrigation agency's ability to respond, in terms of water allocation and delivery in the main system, to diversification once the external environment is encouraging farmers to do so. It was agreed that changes should be introduced in the planning, implementation, monitoring, and evaluation procedures being followed by the irrigation agency.

With regard to water distribution, reliability of timing may be more important than trying to meet adequacy. Rotational irrigation in some form is almost inevitable because of the risk of overirrigation and the need to maintain the hydraulic head, and because rationing by time is easier than rationing by discharge.

Irrigation systems that are properly designed and constructed for implementing irrigation for wet-season rice, and that can meet the land-soaking and land preparation requirements, do have sufficient canal capacity for irrigating nonrice crops, although the need for greater canal water regulation is apparent.

Rotation plans should be known by all concerned. Irrigation system managers should have different plans for different levels of water deficit. The level of rotation at different levels of the irrigation system, depending upon the nature and severity of the water shortage, needs further rationalizing to improve reliability and equity. It was clear that the development of new rotational plans is a gradual process involving negotiation and testing. The selection of alternative rotation plans is a contract between the irrigation agency and the farmers. The activities should be based on suitability for farmers (time of delivery/nondelivery), manageability by agency (staff, number of gates, etc.), and technical feasibility (conveyance capacity, cross-regulation provision).

There should be an early warning in case of a change in the rotational plan, and this should be done through a concerted effort to maintain communication between the agency staff and the farmers.

The information management required should include the monitoring of the dynamic situation at the intake (available river flow and diverted flow to the system), and the overall implementation of the plan. Regular meetings between the irrigation staff and farmers or their representatives during the implementation of the plan should serve as a means for monitoring the operations of the system. The meetings could provide the feedback mechanism needed to make the schedule more realistic and to settle conflicts in water distribution.

The involvement and participation of farmers as early as the planning stage (annual seasonal planning) is implied, and should be institutionalized to minimize problems during implementation. The active participation of farmers in decision making and in managing the system increases their awareness of the system's capabilities and helps them to understand the plan and the reasons for actions taken.

The objectives of the plan (in terms of production, equity, sustainability, etc.) should be clear to all concerned and need to be translated into clear operation rules.

Water availability prediction must be accurate. If available water is below the demand, rotation between years (i.e., 2-3 year planning cycle rather than 1 year) may be appropriate.

Farm-level water management. There are many factors influencing the options for changes in rice-based farming systems, and these include availability of adequate water, land suitability, climatic condition, availability of management technology, time constraint caused by the presence of rice crop, farmers' preferences, resource base, influence of neighboring farmers or extension agents, and land tenure status. Income stability, however, was identified as the major consideration that influences the farmers' decision whether or not to diversify.

In responding to the changes, it is implied that farmers must assume greater responsibility in water sharing to bring about the desired changes in water management. Some checking facilities may have to be added to provide the hydraulic head

required at certain points, in order to implement the flush basin flooding method for irrigating a number of crops such as onions, tobacco, etc. Additional facilities are needed during the dry season, in the form of extra field channels to facilitate the distribution, application, and removal of excess water for nonrice crops. The resulting density of the field channels can be more than three times that presently retained for rice cultivation during the wet season.

The use of groundwater to supplement canal supplies in the dry season was significant and economically attractive in both the Indonesian and the Philippine sites. The same result is expected in similar groundwater use for rabi (dry) season cropping in the Ganges-Kobadak Irrigation System area in Bangladesh (see Chapter 6).

The use of residual soil water is significant in Bangladesh for growing wheat, onion, garlic and legumes after the aman (wet) season in the Ganges-Kobadak Irrigation System (Bangladesh) area. While the potential is present in Indonesia and the Philippines, the use of residual soil moisture, especially for mungbean, has not been systematically documented.

The challenge of managing a high water table, resulting from seepage from adjacent unlined canals and surrounding fields, has been addressed in the Upper Talavera Irrigation System (UTRIS) site in the Philippines. A properly designed interception-cum-drainage channel was established around and across the average-sized fields to convert an unsuitable area to produce maize of 7.3 tons/ha, compared with 3.3 tons/ha in the control area.

It was found that a cropping pattern of rice-mungbean-maize, replacing rice-rice-nonrice, has higher productivity than rice-maize-mungbean for systems without adequate irrigation. In Bangladesh, green manure-rice-legume is recommended to replace rice-rice.

Optimal yields for nonrice crops are obtained if soil moisture depletion is not allowed to go beyond 40 percent of the available soil moisture.

Economics and institutional issues in irrigated rice-based farming systems. Different cropping options that the farmers may consider during the dry season were identified. These include leaving the land fallow, planting only nonrice crops, growing combinations of nonrice crops or rice and nonrice crops, and planting a dry-season rice crop. These options are influenced by a variety of factors such as crop scheduling/timing, tenural status, prices of inputs, product (market) prices, land suitability, drainage constraints, farmer experience/attitudes, agency staff skills, labor/farm power, farmers' ability to control water, access to technology, government policies, and the presence of residual soil moisture.

The implications of changes in irrigation management, as earlier indicated, include the need for better coordination among farmers, between farmers and agency staff, and among agency staff to increase the reliability of irrigation delivery. The conjunctive use of surface water and groundwater needs to be enhanced, and information on drainage should be considered.

These implications could be addressed through a pilot testing of management changes and an assessment of successful cases. These would involve the agency, farmers, and researchers interacting to fine-tune management procedures in the

internalization process while the participation of the researchers is gradually phased out. The budget implications of the new management changes need to be assessed.

Critical issues discussed. Irrigation service fees. Policies on irrigation service fees should be reviewed in relation to the differences in managing the system for rice versus nonrice crops. Consideration should be given to farmers who use water more efficiently, or who practice water conservation measures such as mulching and water augmentation. It was suggested, however, that the review might also look at strategies to encourage farmers to pay irrigation fees.

Tenural status: The status of land tenure has implications for farmers' attitudes towards improving land productivity. Not owning the land appears to deter farmers from using the recommended technologies in their farms. Landlord-tenant arrangements also cloud the issues of membership in Irrigators' Associations and payment of irrigation service fees. Is the landlord or the tenant responsible? Similar confusion will arise over improving land productivity through crop diversification.

Farmers' decision to diversify: As the report indicates, several factors influence the decision of the farmers to plant rice or nonrice crops, and some degree of flexibility is needed. However, this flexibility should take into account not only the farmer's own advantage but also the effects on other farmers and the flexibility of the irrigation system itself. It may be necessary for the irrigation agency and other support services to be ready with options that match the requirement of not individual farmers but of a group of farmers. The agency should also have some kind of mechanism to influence the farmers.

Farmer organizations: Organizing farmers is not an absolute necessity for effective irrigation management. In Pakistan, the farmers use the water as they see fit. However, this cannot happen in the Philippines, Indonesia or Bangladesh, where farmers have no fixed water rights. Here, responsibility needs to be shared between the farmers and the agency. The specific sociopolitical situations must be taken into account.

PLANS FOR THE IMMEDIATE FUTURE

The preparation and publication of the national and the intercountry workshops proceedings will be done during the first half of 1991. An end-of-project report will also be prepared.

Outstanding or unresolved issues such as the following may be addressed in future research:

- Is the design of the irrigation system with flexibility for crop diversification more complex?
- How can assessments of available water supply and water demand be improved to match the demand under diversified cropping conditions?
- Should the government become directly involved through such mechanisms as crop plans?
- How should the agency and farmers cope with different soils/drainage environments, considering zoning and water requirements?

- For both rice and nonrice production, how should better techniques be developed for improving water use efficiency and productivity?

RECOMMENDATIONS FOR FUTURE ACTION/RESEARCH

The various papers presented, the reports of the workshop groups, and the discussions throughout the workshop all highlighted one point — the Project may be completed but much remains to be done. Useful information and technologies have emerged and these are expected to enhance irrigation management. The participants strongly felt that these should be further evaluated through some kind of piloting activity. It is anticipated that a gradual internalization process will be needed for the impact of the recommended innovations to be really felt.

An action plan is needed to put the findings into operation. Stronger and more active participation by the irrigation agencies and the farmers is envisioned. Other agencies involved in agriculture (from production to marketing) should also be included. The involvement of the research group will become less and less as the recommendations are adopted and institutionalized.

Research is a dynamic process, and the Project has provided ideas and areas for further research. The question of drainage, in particular, requires further study, as the provision of basic drainage facilities is essential, especially for upland crops. Farmers' motivation to participate in irrigation management should be studied more deeply than the need to form associations. The agency-farmer relationship is a necessary part of diversification, and it still has a long way to go. A measure of reliability in water delivery is also important for crop diversity, and this remains to be developed. Market forces and postharvest facilities should also be given due consideration.

In implementing these recommendations, the role that IIMI and IRRI have to play is still apparent. Collaboration between agencies has proved to be very positive, and this should be sustained. Other agencies have been suggested as potential participants, particularly in the piloting activity. Interested donors should also be identified.

Research Network on Irrigation Management for Crop Diversification (IMCD)

DURING ITS THREE years of activities, the tri-country IIMI/IIRI collaborative Project has addressed important and comprehensive issues of irrigation management for nonrice crops in rice-based systems. The next step is to evolve strategies to operationalize the recommendations that have come out of the present findings, and to disseminate the information as widely as possible to irrigation and agricultural agency officials. The research network on Irrigation Management for Crop Diversification (IMCD), organized on IIMI's initiative, will be very useful for this purpose.

The idea of forming this network was approved in principle by the participants in a regional workshop on irrigation management for crop diversification organized by IIMI in Sri Lanka in November 1986. Eight countries had already signified their interest in joining the Network - namely Bangladesh, India, Indonesia, Nepal, Malaysia, the Philippines, Thailand, and Sri Lanka. The planning and organization of the Network took place later during an ADB-funded workshop held in early December 1988 in Bangkok. The Network links researchers, irrigation and agricultural agency officials, and others concerned with irrigation management for crop diversification. With financial assistance from the Government of Japan, the Network attempts to serve as a mechanism for research and information exchange in:

- Comparing differences and similarities in national objectives concerning irrigated crop diversification in rice-based farming systems.
- Determining existing irrigation management technologies for nonrice crops at the main system, tertiary system, and farm levels.
- Identifying technical, institutional, and economic potentials for diversified cropping in general, and for selected crops in each country or region under irrigated conditions.
- Determining and evaluating alternative practices and technologies to match national objectives and goals.

A Steering Committee, consisting of selected representatives from each of the eight countries and IIMI, oversees the operations of the Network. The elected Committee Chairman, with the heads of the subcommittees on research and development, information and dissemination, and funding, presents for the committee's review and approval, the program of the activities for the year. IIMI provides the secretarial support.

The inaugural meeting of the Steering Committee was hosted by the Department of Irrigation and Drainage (Malaysia) in Kuala Lumpur in 1989, and it paved the way for putting into operation the objectives of the network as agreed during the 1988 Bangkok workshop. The subcommittees on research and development, information and dissemination, and funding presented their respective programs of activities for 1990.

The maiden issue of the IMCD Newsletter came out in August 1990. The Newsletter will be published annually to facilitate information exchange and dissemination on the subject of the Network. It is intended as a forum for Network members to exchange experiences, views, news of new publications, workshops, etc., as well as for publishing short abstracts of relevant research. The first issue featured highlights of the committee meeting in Kuala Lumpur, and such ongoing projects as the Crop Diversification Project for Non-Granary Irrigated Areas in Malaysia, the NIA Diversified Crops Irrigation Engineering Project and the IIMI-IRRI Collaborative Project.

The formation of national committees such as the National Committee on Crop Diversification (NCCD) in the Philippines, is being catalyzed to link up with the Network. The memorandum of agreement binding five national departments was signed recently.

The Network's activities in 1990 culminated in its first annual review and coordination workshop during 10-14 December in Manila, under the theme of "Management Arrangements for Accommodating Nonrice Crops in Rice-based Systems."

FUTURE PLANS

Future plans include the holding of the second annual review and coordination workshop in Indonesia. The venues for subsequent meetings will rotate among the network countries to give the participants a chance to visit and observe the activities in each country. Publication of the second volume of the IMCD News and the Proceedings of the December 1990 Manila workshop is planned. The formation of parallel national committees on crop diversification, similar to the NCCD in the Philippines, will be promoted in the other member countries. It is expected that one will be formed in Bangladesh soon.

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CHAPTER 6

Studies on Rice-Based Irrigation Systems Management in Bangladesh

Donald E. Parker

INTRODUCTION

IRRIGATION SYSTEMS IN Bangladesh are primarily oriented to the production of rice. Rice is grown in three overlapping seasons: *aman,* or rainy-season rice for which supplemental irrigation is often useful; *boro,* or winter rice; and *aus,* grown during the hot spring and early summer. The types of irrigation systems used for rice are quite varied, and include tubewells, canal systems and low-lift pumps drawing water from surface sources. Recent growth in irrigation has been most noticeable in the tubewell sector, as Bangladesh has large groundwater resources which, in most places, are amply replenished during the monsoon season. Large numbers of wells and canal command areas, however, are underutilized, raising questions as to how they can be more productively and equitably managed. It was in this context that the Bangladesh portion of the IIMI/IRRI collaborative project on problems of irrigation management for rice-based farming systems was started.

The Bangladesh component of the IIMI/IRRI collaborative project has had a somewhat different emphasis from the components in Indonesia and the Philippines. In those countries the focus has been on irrigation management for diversified cropping, whereas in Bangladesh the emphasis has included the management of irrigation systems for rice whether or not other crops are grown. Nonrice crops do have an increasing significance in Bangladesh, but the country is not yet self-sufficient in rice and the general efficiency and equitability of its irrigation systems would appear, at this time, to be of the greatest importance.

IIMI's partnership with IRRI in Bangladesh had to await the arrival of the IIMI Resident Scientist in Dhaka in late 1988. Since 1982, IRRI has already been sponsoring some on-farm irrigation work in two projects through the Bangladesh Rice Research Institute (BRRI). Those two projects, plus one new site, were selected for the collaborative work. IIMI's part of this collaborative work was designed during 1989, but actual data collection started only with the dry season of 1989/1990, due to problems in arranging the deputation of a researcher to lead the work.

The BRRI team with which IIMI has worked on this program concentrated most of its efforts on issues that could be termed on-farm. These included water availability

and utilization, fertilizer-water interactions and crop diversification demonstrations. They also examined main system possibilities of reusing drainage water for irrigation as well as of rescheduling the major lift pumping schedule within the Ganges-Kobadak canal project.

While the IIMI and BRRI teams worked closely together at all of the research sites, the emphasis of the IIMI group was more exclusively on systems management aspects of irrigation. The overall objective of the IIMI studies was to examine the constraints on better command area utilization and equity with a view towards identifying and, when possible, monitoring management changes that could relax those constraints. The specific studies undertaken included:

- The examination of an experiment in water rotation in the Ganges-Kobadak Irrigation System.
- The monitoring and assessment of a minimum irrigated acreage rule applied by the North Bengal Tubewell Project to increase command area utilization.
- A study of irrigation service fees and collection efficiency under various types of irrigation systems.
- A comparison of tubewell irrigation under a number of different management regimes.
- A look at farmer organizations in irrigation management in several types of systems.

The aim of this paper is to briefly present a selection of the findings from the studies undertaken primarily by the IIMI portion of the IIMI/IRRI collaborative program in Bangladesh. Of the above subjects, all but the last will be presented as separate sections. Issues of farmer participation and organizations permeate the discussions of the other topics. Studies conducted predominantly by the BRRI (IIRRI) portion of the collaborative IIMI/IRRI research team are reported elsewhere.[22]

STUDY LOCATIONS

Studies were conducted in three locations in Bangladesh. The Ganges-Kobadak Irrigation System operated by the Bangladesh Water Development Board (BWDB) is a major lift canal system pumping from the Ganges and having 145,000 ha of irrigable command area. Originally designed only for supplementary irrigation during the aman season, the system now pumps from February until November, covering both aus and aman. Sufficient water cannot be pumped to cover the whole of the command area, particularly during aus. BRRI has studied irrigated rice cultivation on nine tertiaries scattered among three secondaries of the project. In addition to working on information from these tertiaries, the IIMI team worked with a fourth secondary (S8K) on which an experiment in water rotation was being conducted.

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[22] See Proceedings of the IIMI-IRRI Intercountry Workshop on Irrigation Management for Rice-Based Farming Systems, Colombo, Sri Lanka, 12-14 November, 1990.

The North Bangladesh Tubewell Project (NBTP), also run by BWDB, is located in the far northwest part of the country. It is composed of 381 deep tubewells installed during the 1960s. The system relies on an electrical grid that has often provided haphazard service. BRRI has intensively studied 12 pilot tubewells and 24 nearby "satellite" wells for several years. For the study of some issues, IIMI used information from these BRRI wells. To examine the implementation of a minimum irrigated acreage tubewell operation rule, the IIMI research team also randomly selected four clusters of tubewells, in each of which four wells were studied.

For further study of tubewells under various non-BWDB forms of management, the IIMI/BRRI research group chose a number of tubewells in the Rajshahi region, located north of the Ganges in the westernmost part of the nation. Six tubewells were chosen in the Barind Integrated Area Development Project (BIADP) of Bangladesh Agricultural Development Corporation (BADC). This project operates about 2,400 deep tubewells. Somewhat to the east of the BIADP area, six tubewells rented by BADC to farmer groups were chosen for study. For three of these six wells the farmer groups were provided with production loans (including irrigation costs) by the Rajshahi Krishi Unnayan Bank (RAKUB), the agricultural development bank. In the same area, three additional wells actually owned by farmer groups were also selected.

RESEARCH DESCRIPTIONS AND FINDINGS

The studies undertaken include two site-specific issues (rotation in the Ganges-Kobadak scheme and the minimum irrigated cropped acreage rule in the NBTB) and two cross-site studies (comparative tubewell management as well as irrigation fees), all of which include elements of farmer participation in irrigation management. It should be emphasized that there are a great number of types of irrigation management systems in Bangladesh and the studies (and sites) dealt with in this paper represent only a few of these types. There are, for example, additional irrigation management schemes run by various NGOs or by landless groups. There are also multipurpose schemes that incorporate flood control and drainage functions. Both time and resource limitations precluded the inclusion of all types of management regimes in this study. This study does, however, include management issues (and irrigation projects) that are of importance in Bangladesh.

An Experiment in Water Rotation in the Ganges-Kobadak (G-K) Irrigation System

As the G-K system is deficient in water relative to the total needs of the farmers within its command area, a nine-day rotation (with three days of flow followed by six days off) among secondaries was rather loosely followed for some years. In 1990, the rotation was changed to one of ten days-five days with water followed by five days without. The IIMI-IRRI-BRRI research group, in consultation and collaboration with the G-K project officials, undertook an experiment on one secondary to monitor the

full implementation of the rotation and examine its results. The action research experiment attempted to resolve a number of problems encountered in the nine-day rotation system. These problems included the non-observance of rotation among tertiaries, the deteriorated condition of the canals and field channels, unauthorized cuts in the canals, the condition of hydraulic structures of some bridges and culverts, the absence of farmer organizations and participation by farmers, and a general lack of communication and interaction between the farmers and the project officials.

The secondary canal chosen for study (denoted as S8K) was one of the more problem-ridden parts of the G-K system. Project officials arranged for repairs to this canal and its control structures, and devised a system that ensured that the (5 + 5) ten-day rotation could be strictly observed in regard to water deliveries to the secondary. Project officials, along with research team members, made special efforts to keep the farmers along the secondary informed of developments and to encourage their participation. In addition to numerous field visits, these efforts included a field workshop held in a centrally located village along S8K. At this workshop farmers were able to voice their concerns and participate in decision-making regarding their (and the project's) responsibilities in the rotation scheme. A good deal of cooperation between farmers and officials, and among farmers of different tertiaries (notably absent in previous years, with head-end tertiaries taking all of the water), followed this workshop.

The impact of the rotation experiment on S8K has been highly positive in terms of area irrigated and equity. Of course, the sustainability of this improvement in future seasons remains to be seen. The impacts are noted in Table 6.1

Area Irrigated. The area irrigated under S8K in the 1990 aus season was 528 ha as compared with 54 ha in the 1989 aus — an increase of 877 percent. On this secondary, 82.8 percent of the 1990 Water Board target was achieved, as against 8.5 percent in 1989. This record of achievement at the macro level is supported by data collected from 77 sample farmers selected from head, middle, and tail locations of each of the four tertiaries of S8K. While the farmers included in the sample cultivated a total of only 1.6 ha of land in the aus season of 1989, they irrigated 20.8 ha of land in 1990 — an increase of 1,170 percent.

Equity. The distribution of water among different tertiaries and among farmers at the head, middle, and tail locations along the various field channels has also become much more equitable in 1990. In 1989, farmers of the tail tertiary (T4) irrigated an area which was only 2.5 percent of all land actually irrigated along S8K in that year. In 1990, their share of the total land irrigated increased to 18.4 percent; so, while this tail tertiary did not quite fulfill its own absolute target it did do well in relation to its upstream tertiary neighbors. The position of T3 farmers also improved dramatically, but not as much as that of the T4 farmers (an improvement from 5.8 percent of total S8K irrigated area in 1989 to 24.8 percent in 1990. The T3 1990 targeted share, however, was 27.3 percent). In addition, the position of tail-end farmers within each tertiary (not shown in Table 6.1) improved substantially in that their share of irrigated land also increased. In 1989, the sample tail-end farmers (on all four of the tertiaries) did not cultivate any

land under irrigated crops during aus. In contrast, these same tail-end farmers irrigated 4.6 hectares of land in 1990 (22.2 percent of land irrigated by the full sample of farmers at the head, middle, and tail sections). In addition, all of the sample tail-end farmers reported that they received sufficient water during the aus season.

Table 6.1. Area irrigated in aus with (1990) and without (1989) rotation along tertiaries of secondary S8K in the Ganges-Kobadak Irrigation Project.

	T1	T2	T3	T4	Total
Target Area (ha) (system data)					
1989	132.4	236.8	178.1	90.3	637.6
1990	121.5	238.5	174.1	103.6	637.7
Actual Irrigation (ha) (system data)					
1989	21.6	28.0	3.1	1.3	54.0
1990	120.4	179.5	130.9	97.1	527.9
Actual Irrigation (ha) (sample farmers)					
1989	0.9	0.3	0.4	—	1.6
1990	4.5	4.8	5.5	6.0	20.8
% Target Irrigation (system data)					
1989	16.3	11.8	1.7	1.4	8.5
1990	99.1	75.3	75.2	93.7	82.8
% Total S8K Irrigation (system data)					
1989	39.9	51.8	5.8	2.5	100.0
1990	22.8	34.0	24.8	18.4	100.0

The success (at least for 1990) of the rotation experiment may be attributed to a number of factors:

- Effective communication and interaction between the farmers and project officials. The early field workshop (organized by the research team) brought farmers together from all parts of the secondary and gave them a forum for interaction and for direct contact with officials.
- Farmer participation. As farmers came to believe that the secondary would get water as scheduled, they were willing to work together on a rotation along S8K. In contrast to previous years, upstream farmers did not destroy the tertiary gates, remove the gauge meters or stop water from going to the downstream tertiaries. Farmers also participated in maintenance.

- Interest and attention of project officials. Both senior and field- level project officials paid attention to the needs of the rotation scheme on S8K and kept in touch with farmers as well as with the researchers.
- Change in the main canal control system. In contrast to previous years, a regulator in the main canal just downstream of S8K was used in such a way as to guarantee the delivery of water to the secondary on time during its five-day turn.
- Favorable rainfall. Rainfall during the 1990 aus season was well distributed over time and is, no doubt, partly responsible for the improved situation along S8K. On nearby (non-rotation-experiment) secondaries, however, the improvements during 1990 were on a much more modest scale, supporting the implication that a large part of the improvement on S8K was due to the rotation program.

These possible explanations do raise the question of sustainability and replicability. Can the G-K project guarantee scheduled water deliveries to a larger number of secondaries? Can project officials pay sufficient attention to localized problems and to farmer concerns in a greater number of secondaries? Will farmers continue to cooperate and participate during future years? To try to answer some of these questions there are plans to study an expanded rotation program in the Ganges-Kobadak system in the 1991 aus season.

The Implementation of a Minimum Irrigated Cropped Acreage Rule for Tubewell Operation in the North Bangladesh Tubewell Project (NBTP)

The results of the other experiment to increase irrigation coverage, a minimum irrigated cropped acreage (MICA) trial conducted in the North Bangladesh Tubewell Project (NBTP), are not as positive as those of rotation in the G-K system. However, as with rotation, this experiment also shows some of the potential for improving system performance through management changes and farmer involvement.

As is the case for a great number of deep tubewells (DTWs) throughout Bangladesh, the wells of the NBTP tend to irrigate much less than their technically practical command areas. Among the reasons for this tubewell underutilization are: a) disruptions in DTW operation due to faulty power supplies, inadequate maintenance, etc., and b) organizational problems with farmers creating severe inequities in access to reliable supplies of water.

To encourage farmers at these tubewells to work together, and to promote more interaction between farmer groups and agency officials, the research project made a policy suggestion that the Bangladesh Water Development Board (BWDB) adopt a minimum irrigated cropped acreage system. Under this system the farmer groups would indent for irrigation water before a given season but the agency would only operate the well if some predetermined minimum acreage was to be serviced. The rationale behind this policy was that it would put pressure on each farmer group to solve at least some of the organizational problems that may have constrained the

spread of irrigation in the past. Those few farmers who, in the past, were normally using tubewell water would have to accommodate other farmers' demands if anyone at all was to receive water. The agency, at the same time, would have to make great efforts to improve the reliability of the operation of those tubewells where a minimum cropped acreage was enlisted for an irrigation season.

Serious implementation of the minimum irrigated cropped acreage (MICA) policy did not begin until the aus season of 1990, when the project officials and the research team made efforts to communicate the new system to the irrigators. Project officials and extension personnel spread the word about MICA, and agency officers and members of the research team also held a series of field workshops aimed at explaining the program and getting feedback from the farmers.

While participation did increase to some extent with the spread of MICA there were also problems, primarily caused by the design of the program. The water demand indent system was easily abused, as farmer groups only had to claim that they would be irrigating the minimum acreage for the water to be turned on for the season. No system was devised for stopping the operation of a well during the season if the number of irrigated acres claimed were not, in fact, irrigated. In addition, the Project's ability or will to enforce sanctions against noncomplying tubewell groups was in some doubt, though a formal test of that ability was avoided due to the manner in which the indent system operated. Table 6.2 shows some of the impacts of the minimum irrigated cropped acreage experiment.

Irrigated Area. Information on irrigated area, both during the 1990 experience with the MICA rule and during previous aus seasons, was available from 16 sample tubewells plus 58 other tubewells scattered around the North Bangladesh Tubewell Project (Table 6.2). Of these 74 wells, 30 met their minimum irrigated acreage targets. These wells had an average MICA target of 16.5 ha but actually attained 20.9 ha. In the 3 aus seasons preceding 1990 these same tubewells averaged 15.2 ha. The average improvement in irrigated coverage was 5.7 ha.[23] Of the 44 tubewells that did not meet their MICA targets (but which were operating because they had originally promised, through the indent system, to meet the MICA target) the average irrigated coverage increased from 6.3 ha in previous years to 7.5 ha in 1990.[24] It is quite possible that the increases in irrigated area can be explained by the MICA rule, or at least by the attention focused on the issue of command area utilization through the MICA experiment. The increases were moderate, however, indicating that the MICA rule by itself may not in its present form have the potential to solve the problem of tubewell underutilization. Another issue is also raised by these figures. It can be noted that the group that did not meet its MICA targets had an average irrigated area in pre-MICA years of only 41 percent of that of the group of wells that actually reached their minimum irrigated acreage targets. These two groups, then, are likely to have had quite different

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[23] Statistically significant at the 1 percent level.

[24] A difference that was statistically significant at the 10 percent level.

characteristics or constraints. In fact, farmers who failed to meet their MICA targets identified poor channel conditions, sandy soils, weak farmer organizations, and the cultivation of wheat in parts of their command areas as reasons for their failure. It is unclear whether target-attaining wells faced these problems to the same degree. To be effective, policies to increase irrigation coverage may have to address these issues, and possible future research might address the better identification of these differences.

Table 6.2. Minimum irrigated cropped acreage (MICA) targets, actual irrigation attained and rice yields during the 1990 aus season in the North Bangladesh Tubewell Project.

	Average MICA target (ha)	1990 Average actual irrigated area under MICA (ha)	1987-89 Pre-MICCA average irrigated area (ha)	Pre/post MICA difference (ha)	Average rice yield (tons/ha)
Wells meeting MICA targets	16.5	20.9	15.2	5.7	5.54
Wells not meeting MICA targets	15.2	7.5	6.3	1.2	4.68

Note: Hectare figures are for 16 sample tubewells plus 58 other North Bangladesh Tubewell Project wells for which data were available. Yield figures are from crop cuts on sample wells only.

Yield. Among the 16 sample tubewells, average rice yield (for the Purbachi variety) was 14 percent higher for farms on tubewells that attained their MICA targets than for those on tubewells that did not. This range of difference was evident at head, middle, and tail locations.[25] Given the possible differences in characteristics of the two groups of tubewells, the yield difference may or may not be due to the implementation of MICA.

Equity. Among sample tubewells neither locational nor farm size equity in terms of irrigation coverage seems to have changed much during the 1990 MICA rule application.

[25] The yield differences between head- and tail-end farmers of both groups were statistically significant at the 1 percent level.

Irrigation Service Fee and Collection Efficiency

The collection of irrigation fees in order to at least cover the operation and maintenance costs of the system has often been put forward as a useful policy. With such fees, irrigation management is expected to improve for a number of reasons: a) The generation of funds can help in the timely provision of O&M functions. b) The sharing of costs by water users can improve the accountability of irrigation managers to water users. c) Water users can be expected to use irrigation facilities more carefully in order to avoid increases in O&M costs that might be translated into increased fees.

In Bangladesh, it is the stated government policy to recover the O&M costs of its irrigation projects. The experience in fee assessment and in collection efficiency varies widely, however, by agency and by type of system and management. The IIMI study team examined various aspects of irrigation fee collection and system management. As can be seen in Table 6.3, there is a great difference between Bangladesh Agricultural Development Corporation (BADC) and private tubewells in the Rajshahi area, on the one hand, and the BWDB canal and tubewell systems on the other. The irrigation fees paid by farmers in the BADC rental wells and in the Barind Integrated Area Development Project (BIADP) system approximate or exceed the level of O&M costs. For the few private tubewells under study the fees (at 208% of O&M costs) obviously make a substantial contribution to capital costs and/or the owners. Collection efficiency, as represented by the percentage of assessed fees collected, is also very high. This picture is in great contrast to the experience in the Ganges-Kobadak and North Bangladesh Tubewell Project. In these BWDB projects the assessed fees represent only a small fraction of the costs of operation and maintenance. Despite the low level of the BWDB fees, the collection efficiency is also very low. Only 1 percent of the fees is actually collected in the G-K project.

A number of factors might explain some of the differences between the fee experiences in the two BWDB projects and the various BADC and private wells under study. Sample farmers in each of these systems were asked a number of questions about their participation in, and understanding of, fee setting and collection. None of the G-K or NBTB (both BWDB systems) farmers had participated in fee-decisions, nor did they seem aware of the criteria used for the fixing of fees. Partly because of the tubewell-centered (as opposed to project-centered) nature of the management of the various types of tubewells under BADC or private ownership, farmers in these systems felt that they had participated in the setting of their fees and were well aware of the criteria used for fixing of fees. Farmers were also asked how fee collection could be improved. All of the NBTB respondents, but very few farmers from other projects, noted that improved irrigation service would be required. Respondents in the BADC and private wells, by contrast, concentrated on issues of improved farmer participation when answering the same question. These responses would indicate that greater farmer participation in fee-decisions (or other aspects of irrigation management), as well as adequate irrigation service delivery, may well lead to a greater willingness to pay for water received.

Table 6.3. O&M costs, irrigation fees, and collection efficiency (Taka figures are per season per hectare).

System	O&M costs	Irrigation fees (Taka)	Fees as % of O&M (Taka)	Collection as % fees
BADC rental DTW with bank loan	2,460	2,287	94	79
BADC rental DTW without loan	2,005	3,273	163	96
BADC, BIADP DTW	4,442	4,810	108	6
Private DTW	1,891	3,929	208	98
BWDB, NBTP DTW	4,426	289	7	24
BWDB, G-K Canals	2,097	329	16	1

Notes:

a) Figures are from sample tubewells in 1989-90 for all but the two BWDB systems where figures are from the project level for 1988-89.
b) Average per season per hectare irrigation fees are calculated by dividing gross yearly fees by gross annual irrigated area.
c) O&M costs include both direct and indirect costs.
d) Irrigation fees are defined as the sum of all payments made by the farmers for the irrigation services they receive. For BADC wells, the agency charges reflect only part of this fee.

In Bangladesh, there is an ongoing movement to privatize small-scale irrigation systems. It is likely that most of the NBTB tubewells will soon be privatized or taken over by the Grameen Bank. Farmers using these wells will then have to manage their own systems and will be forced to pay their own O&M costs — though perhaps not without a struggle, as irrigation charges have been the main item of friction in the wells already taken over by the Grameen Bank's irrigation management system. For canal systems such as G-K, however, improvements in fee collection may not be so easily solved. In some of its other surface projects, BWDB will soon be experimenting with ways of passing the responsibility for fee collection over to outlet committees. It will be useful to follow these experiments in farmer participation and assess their results.

Deep Tubewell Irrigation Under Different Management Regimes

The Rajshahi area was chosen for study because it provided an opportunity to examine tubewells under a variety of ownership/management situations. The cooperation of the Rajshahi Krishi Unnayan Bank (RAKUB) also provided the chance to examine a

program for the provision of production and irrigation management credit as it might operate under the various management regimes under study. RAKUB was to extend its credit program to include a number of wells under the BIADP scheme, under BADC rental arrangements, and under private ownership. Within each management category, the IIMI/IRRI research group was to study several tubewells within, and several outside, the RAKUB credit program. Unfortunately, as the irrigation season got under way, RAKUB proved unable to extend its program beyond the BADC rental category, and the irrigation management credit part of the study lost much of its credibility. It was still possible, however, to compare aspects of irrigation performance for the various categories of tubewell management. These types of ownership/management included:

- *The BADC's Barind Integrated Area Development Project (BIADP).* In this project, informal farmer groups are provided with wells and are required to pay an irrigation charge based on estimated command area. The BADC provides repair and maintenance services up to a value of one third of the charge. The farmer groups collect a fee from the irrigators to bear the costs of the BIADP charge, any further repairs, all fuel and oil, and also to pay the salaries or honoraria of the tubewell managers, operators and drainmen. Management responsibilities lie with the farmer groups or their leaders, but BADC retains enough control of the wells to ensure that its irrigation charge is paid by the groups.

- *The BADC rental program.* The BADC also owns a number of deep tubewells under its rental program. These wells were installed between 1967 and 1978 and were rented to farmer groups (both formal and informal). In the 1980s, BADC attempted to sell the wells to the groups but this effort was largely unsuccessful, and the rental program continues. The farmer groups owe BADC an annual rent of Taka 5,000. The groups are responsible for the costs of operation and maintenance. The BADC retains some repair responsibilities but has little control of well management. While the tubewell managers collect fees to cover O&M as well as the rental charge, the rent seldom seems to reach BADC.

- *Private ownership and management.* Since 1979, the government has been selling deep tubewells (at subsidized rates) to farmer groups, which are then responsible for all aspects of operation and management. Most of these farmer groups exist in name only, with the wells effectively being owned and run by one individual or a few individuals. Capital loans were taken out to purchase the wells, but the level of loan repayment is very low — despite the fact that the fees paid by farmers are sufficient to pay the loan instalments as well as O&M costs.

A number of tubewell characteristics and performance indicators were examined by the study team. This paper concentrates primarily on irrigation coverage and, to some extent, on yield and equity.

Table 6.4. Deep tubewell irrigation coverage and rice yields in various systems in the Rajshahi area during aus of 1990.

Type of system	Area irrigated (ha)	Cusec discharge	Area per cusec (ha)	Operational hours	Water per irrigated ha (meters)	Yield per ha (tons)	Net return per ha (taka)
BIADP DTW	11.4	1.1	10.3	893	0.88	5.89	18,407
Private DTW	23.7	1.7	14.1	626	0.46	4.12	13,551
BADC rental with RAKUB	22.8	1.6	14.0	696	0.49	3.85	12,132
BADC rental w/o RAKUB	21.6	1.6	13.2	675	0.51	3.82	11,652

Irrigated area. The figures in Table 6.4 indicate that the BIADP tubewells irrigated roughly half as many hectares as the other types of wells during the aus season of 1990. When controlling for measured discharge (which is lowest for BIADP wells) it can be seen that the irrigated coverage per cusec capacity was about three quarters that of the others. The BIADP tubewells, however, were operated for a significantly larger number of hours during the season, resulting in 72 percent to 91 percent more water per irrigated hectare than in the other systems. Considering that the soil in the BIADP area was clay, with very low seepage percolation characteristics compared with the medium seepage percolation loam in other systems, the BIADP wells would seem to have very low relative irrigation coverage indeed.

Yield. Farmers using the private wells and those using the BADC rental tubewells mainly grew the *Purbachi* variety of rice, whereas the BIADP farmers chose IR-20 (a slightly higher yielding variety than Purbachi when grown under similar conditions). The BIADP farmers used more fertilizer and water per hectare (as noted above) than did the BADC rental and private tubewell irrigators. The result was that the BIADP farmers reported rice yields and net return per hectare that were 50 percent greater than those achieved by farmers on the other types of wells.

Equity. In none of the systems did distributional equity between actual irrigators (either by location or farm size) seem to be a major problem. In general, all categories of irrigators received adequate and timely supplies of water. However, larger farmers in all of the systems did dominate tubewell management positions, and further information is needed on those farmers who were unable to get irrigation water.

Differences in well capacity, soil, etc., would not seem to be sufficient to explain the very great differences in performance between the BIADP tubewells and those that were privately owned or rented from BADC. Further research is necessary on this subject, but a possible line of enquiry might concentrate, in part, on the enterprise focus of those who dominate the management of the various wells. In all of the wells

under study, the locus of control of water distribution is at the tubewell (rather than project) level. Because of this local control, the irrigators seem well enough informed about various aspects of irrigation such as who will receive water, the setting of fees, etc. There is a difference between types of well, however, with respect to how much those who dominate the management of the wells (whether or not they are actual owners) can make from the operation of the tubewells.

Examining irrigation fees in relation to O&M costs reveals that the private wells, and many of the BADC rental wells, generate a large surplus in the way of fees. As the rental charges and capital loans are seldom actually paid to BADC or the banks this means that those people who dominate the management of their tubewells can generate some personal income from the wells. Their emphasis might be expected to be on running the tubewell as a business and attempting to maximize the tubewell enterprise profit. The enterprise focus of those who run the BIADP tubewells, however, would appear to be on their own farm businesses. As the BIADP system seems to have the power to enforce a high degree of payment of its tubewell charges (unlike the rental tubewells), it is possible that BADC has sufficient influence in the BIADP wells to control the level of fee collected by the local tubewell management groups.

If this is the case, then the local tubewell management of BIADP wells would have little scope for appropriating much in the way of profits. They would do better to try to maximize returns from their own farms, perhaps by concentrating water deliveries on a much smaller command area (including their own land) than would be the case if the tubewell enterprise was their focus. This they seem to have done. The enterprise focus (tubewell versus farm) of tubewell managers may explain part of the difference in irrigation coverage (and yield) between types of systems.

CONCLUSIONS

This paper has summarized some of the findings of several different studies. Three of these have focused on command area utilization, yield, and equity under various irrigation systems or management changes. Another study has concentrated on irrigation fees in all of the systems. Common to all of these studies is the role of farmers and farmer managers (or "owners") in making decisions, in cooperating (or not), or in just reacting to the opportunities created by the actions of others. Inclusion of farmers in the operation of the G-K rotation scheme seems to have been associated with the success of that program. Increased farmer cooperation was to have been a driving force in the NBTP minimum irrigated cropped acreage program but as the MICA rule could be easily circumvented with false water demand indents, that cooperation was never elicited. In the Rajshahi area most wells are dominated not by the irrigation agency but by one farmer or a few of them who are de facto owners. It is these farmer managers, in reacting to the opportunities before them, who determine the irrigation performance of their tubewells. In the case of fee collection it again seems to have been farmer involvement in fee setting and collecting that has helped determine success or failure.

More research is needed in all of these areas, as noted in the individual subject discussions presented earlier in this paper. As Bangladesh moves further into the privatization of its small-scale irrigation systems, the participation and behavior of farmers and farmer/manager/"owners" will become more and more important to performance, particularly to the nature of command area and utilization, a priority in the nation's irrigation program.

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PART 3

Emerging Issues and Trends

CHAPTER 7

Issues in Conjunctive Management of Groundwater and Surface Irrigation Systems in Punjab, Pakistan: An Initial Assessment

Robert L. Johnson and Edward J. Vander Velde

ALTHOUGH THEY ARE much less readily visible (and often less frequently recognized) than the huge network of canals commanding 14-15 million hectares (ha) of the Indus Basin, groundwater irrigation systems have become a major, even critical, component of Pakistan's contiguous irrigation environment. Over very large areas, the surface irrigation system is supplemented by extensive public and private sector groundwater development. Where groundwater is of suitable quality and is readily available, both large public tubewells and rapidly expanding private tubewell development augment surface irrigation supplies. There are now more than 15,000 deep, vertical drainage public tubewells throughout the Indus Basin. Mostly organized in Salinity Control and Reclamation Project (SCARP) areas, these tubewells are operated by the provincial irrigation departments, but under units separate from those that administer the surface irrigation system. The number of shallow private tubewells owned and directly operated by farmers has increased rapidly in the past decade and now certainly exceeds 250,000.[26] Overall, it is estimated that 40 percent of the irrigation water currently available at the farmgate is derived from pumped groundwater, three-quarters of which is from privately owned tubewells.

The resulting irrigation environments can perhaps be best characterized as ones where de facto conjunctive use of surface water and groundwater irrigation systems predominate. However, the ways in which current private and public tubewell operations intersect with canal system operations in these environments, complementary to or even conflicting with each other, remain poorly understood. There is still in Pakistan a marked absence of reliable, current, empirically based information on private tubewell location, discharge, service area and hours of operations, and virtually none organized on the basis of a major hydrologic or surface irrigation unit, such as a distributary command. In the case of public tubewells, while their locations are well-

[26] See Robert Johnson, *Private Tube Well Development in Pakistan's Punjab: Review of Past Public Programs/Policies and Relevant Research* (IIMI Country Paper-Pakistan No. 1, 1989) for a recent summary review of past government programs aimed at stimulating private tubewell development, as well as emerging issues in this irrigation sector.

known, recorded data of their discharge, operating times and command area have become increasingly suspect.

Not surprisingly, then, the relative proportions of publicly and privately pumped groundwater that are combined with surface water by farmers to meet their crop water requirements, in different seasons and for different crops in a canal command, are largely unknown. How do these proportions vary spatially over an entire distributary or canal system command? To what degree, if any, do public and, perhaps more importantly, private tubewell operations compensate for the observed variability and inequity in the distribution of surface supplies? These and related questions of groundwater quality, public tubewell turnover and farmers' access to private tubewell water are the foci of IIMI research begun in January 1988 on groundwater irrigation systems and their interactions with surface irrigation systems in a distributary command of the Lower Chenab Canal system.

THE RESEARCH LOCALE: CONTEXT AND DATA

The site chosen for initial research activities on groundwater systems was the Lagar Distributary command in the Lower Chenab Canal system where previous field work, focusing upon distributary-level canal performance, had already demonstrated that public and private tubewell development were significant components of the overall irrigated agricultural system. The research locale is wholly within a part of the SCARP I project area, the first Salinity Control and Reclamation Project to be established in Pakistan, in 1960-61. Part of the distributary command traverses the area of the older FAO-assisted Chuharkana public tubewell scheme, one of several early deep tubewell projects in Punjab that led directly to the decision to embark upon the SCARP.

More than 30 operating SCARP I tubewells, as well as Rasul and FAO tubewells (virtually all of which are rebores of previously existing public tubewells), are situated within Lagar's gross command area of 7,465 ha. These wells are under the operational control of the Punjab Irrigation Department (ID) and are located within the administrative boundaries of one or another of three different tubewell subdivisions, all of which overlap some part of the ID's Farooqabad (canal) Sub-Division. A portion of one ID tubewell subdivision, Khanqah Dogran Sub-Division, is the site of the SCARP Transition Pilot Project, the initial effort in a Federal program to turn public tubewells over to the private sector.

With respect to irrigated agriculture patterns, the research locale is situated in Pakistan's rice-wheat agroecologic zone. Rice, especially basmati rice varieties, is the predominant crop of choice in the *kharif* (summer, monsoon) season, and wheat dominates the winter and drier *rabi* season to an even greater extent. Fodder crops are an important component of the total cropping pattern throughout the year. All crops are grown under irrigated conditions with water supplied variously from surface, public tubewell and/or private tubewell systems.

The first step in this research was to plan and implement a tubewell census that covered all of Lagar Distributary command. Data from this census were compiled on a watercourse command basis and they included the specific location of the tubewell

(using the unique square and *kila* number assigned to every field in the landownership record), the type of tubewell (electric, diesel, or tractor power takeoff), its age and operational status, and other supplementary information. Completed in early 1988, the initial Lagar tubewell census has been updated by periodic resurveys. This is the first time in Pakistan that a census of private tubewells has been organized for the whole of a large operational unit of the surface irrigation system. Similar censuses were also completed in four IIMI sample watercourses in the neighboring Mananwala Distributary.

The census results provided the basic sampling frame for a program to monitor the operations of all private tubewells in each of four watercourse clusters within Lagar Distributary command. One group of three watercourses, plus an intervening area commanded only by a public tubewell, represents the top-end of the distributary; a second cluster of four watercourses is in the middle reach of the channel; a third cluster of four watercourses is at the tail; lastly, a group of three watercourses is in the command of Jhinda Minor, a small channel offtaking from Lagar about half-way down the main distributary. All operating public tubewells in Lagar Distributary command were also included in the monitoring program which began in mid-1988.

The Irrigation Research Institute (IRI) of the Punjab Irrigation Department joined IIMI in these research activities in late kharif of 1988, in a measurement program to determine tubewell discharges, drawdown, horsepower, and water quality of all tubewells, public and private, that are being monitored. Discharges of surveyed tubewells have been periodically remeasured, using fluming and coordinate methods, by IIMI field staff. Tubewell water quality was initially evaluated at the Department's Directorate of Land Reclamation (DLR); subsequent water quality analyses for resampled tubewells have been done both by DLR and the SCARP Monitoring Organisation (SMO) of the Water and Power Development Authority (WAPDA). Additionally, with IIMI support, IRI conducted a resurvey, in mid-1989, of the small sample of private tubewells in Sheikhupura District first studied and subsequently reported upon by the ID in the mid-1970s.

Tubewell operational data have been obtained by IIMI through several methodologies. Electric meters of operating public and private tubewells (many do not function at all!) have been individually calibrated and are periodically recalibrated for each tubewell to determine the number of units recorded per hour of well operation. Readings of these meters are then regularly recorded by IIMI field staff, and operating hours of those tubewells are determined through a simple arithmetic calculation.

Operating hours of other public tubewells and both electric and non-electric private tubewells have been obtained by installing a simple vibration meter (similar to a pedometer) to the discharge pipe or, in some cases, to the motor of the wells. When operating properly, these meters give a direct reading of operational hours (within +/- 3 percent) of the tubewell. However, in some instances, notably in the case of electric motors, well operation is so smooth that the meter does not vibrate sufficiently to accurately record operating time.

Finally, for many private tubewells, owners are systematically interviewed by IIMI field staff to determine the time that their tubewell was operated the previous day. This is done on a daily basis because, after several months of interview, methodology testing and independent verification, it was found that the accuracy of responses to

questions on tubewell operations declined precipitously if the owners were interviewed more than a day after the operation.[27]

A subsample of 45 private tubewell owners in head, middle, and tail watercourse commands of Lagar Distributary was selected in order to identify and quantify the determinants of private tubewell utilization at the farm level. After extensive field-testing of research design and methodology during rabi, 1988-89, data collection for this research was begun in the 1989 kharif season. Detailed water budgets have been maintained for each tubewell owner's farm. Closely coordinated with this study, field investigations were also begun in order to determine more accurately the accessibility of private groundwater resources for those farmers who do not own tubewells. Results from these activities are not available as yet since field work on them has only just been concluded.

THE GROUNDWATER IRRIGATION SYSTEM WITHIN A SURFACE SYSTEM

As of May 1989, 338 private operational tubewells and 37 public tubewells, of which 31 are operational, were installed in the gross command area of Lagar Distributary. Another 54 operational private tubewells and 4 operational public tubewells have been identified in the four watercourse commands on Mananwala Distributary. All public tubewells are electricity powered using turbine pumps and have bores that are much deeper, (about 90 meters [300 feet]), than those of private tubewells, which are at an average depth of 30 meters (100 feet). Each public tubewell is ostensibly under the operational control of an assigned tubewell operator, an employee in the ID's tubewell operations wing. Most tubewell operators, however, are rarely at the wells for which they are responsible, although public tubewell operational logs give the impression that they are at the right places at the right time.

Tubewell Distribution

The census revealed that throughout Lagar command, there is an average of one private tubewell per 22 ha of gross command area (GCA)[28] or one per 19.5 ha cultivable command area (CCA). Expressed another way, there are about 45 private tubewells

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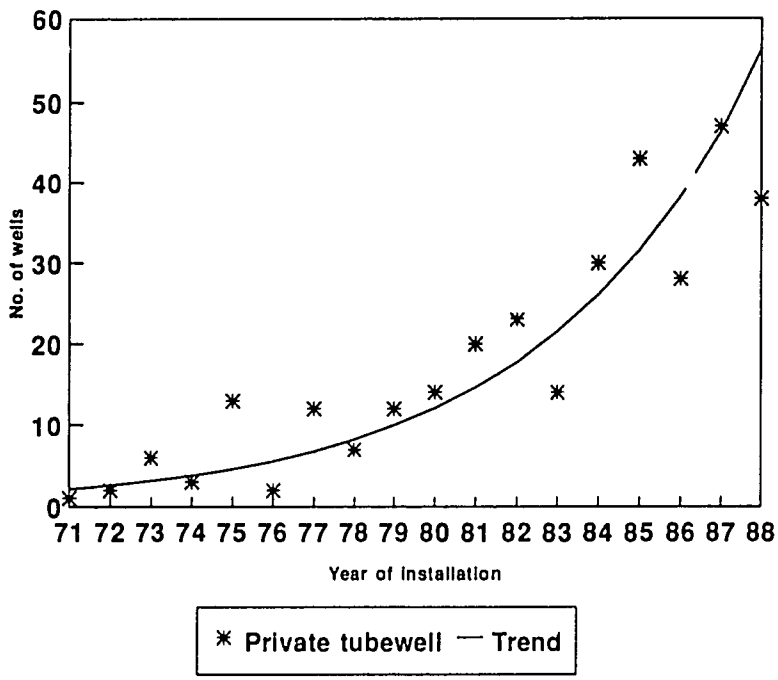
[27] That finding, verified through interviews with respect to several other agricultural activities, has important methodological implications for the organization of much irrigation-related field research, at least in this area of Punjab if not elsewhere in Pakistan.

[28] Watercourse gross command area (inclusive of irrigable area, nonirrigable area, settlement area, etc.) is used here, along with cultivable command area or CCA (irrigable by surface irrigation) because many tubewells were installed to serve areas that could not be irrigated by the surface system and, hence, are not (or were not previously) classified as CCA.

per 1,000 ha GCA or nearly 51 per 1,000 ha CCA. The density of tubewells in the smaller Mananwala sample is somewhat higher than in Lagar Distributary command, with an average GCA per tubewell of about 16 ha (or slightly less than one per 15 ha CCA). These densities are about 50 percent greater than those indicated by the most recent survey of private tubewells in this area, done as part of the feasibility study for the SCARP Transition Pilot Project in 1984-85.

During the 1980s there has undoubtedly been an increase in the number of new private tubewells in Punjab. Figure 7.1 shows this trend for Lagar Distributary command based upon farmers' responses to questions about the year of tubewell installation. The apparent growth rate in the number of tubewells also needs to be balanced with data on the useful life and the proportion of new tubewells that represent replacement of existing wells. These data are not now reliably available, although a period of 7-10 years is frequently cited as the life expectancy of a private tubewell. It also seems likely that private tubewell densities may have been

Figure 7.1. Growth of private tubewells: Lagar Distributary command.

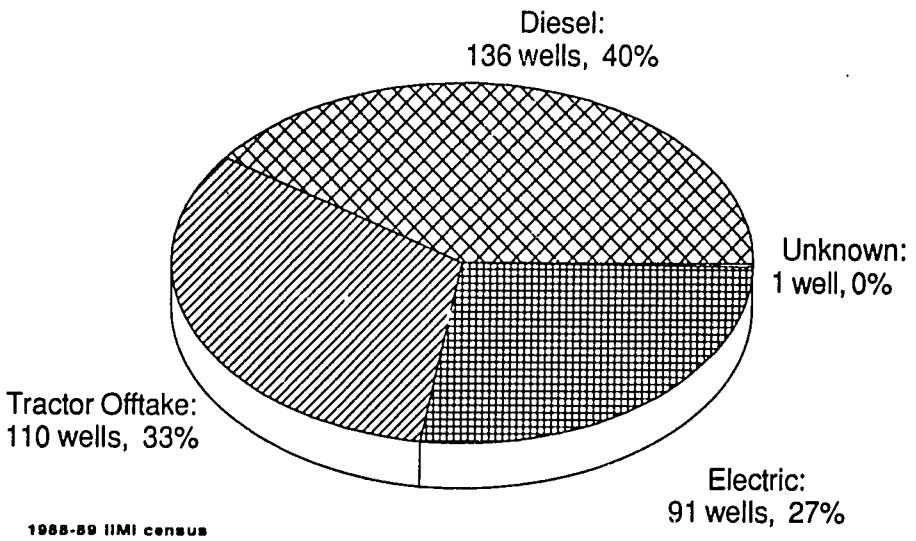


understated in recent studies because of difficulties in the accurate field enumeration of tractor-driven wells, which constitute nearly one-third of all tubewells identified in the IIMI census (Figure 7.2).[29]

Tractor-driven private wells seldom appear to be those of farmer choice, but they are especially interesting for several reasons. They have the lowest installation costs, excluding the cost of the tractor, but the highest operating costs. Despite their high operating costs, there are many locations where tractor-powered wells are the only source of irrigation water for farmers, and, among all tubewells, the variety of arrangements among farmers for their operation is by far the greatest. These include tractor ownership and ownership of one or several bores, tenant ownership of the bore with the landowner providing the tractor, farmers sharing a tractor among their own bores, farmers sharing a bore but each providing his own tractor, and bore-owners renting tractor services.

The spatial density of private tubewells in each watercourse command of Lagar Distributary is shown in Figure 7.3 and Figure 7.4. The data reveal no clear trend toward an increase in private tubewell density between distributary head and tail, even

Figure 7.2. Private tubewells by power source: Lagar Distributary command.



[29] Tractor-driven wells typically consist of a shallow hole at the base of which the bore is made and a centrifugal pump is installed; a discharge pipe with a 90° bend then extends from this point a half-meter or so above the surrounding land surface. When such crops as sugarcane, cotton, wheat, rice or maize are approaching maturity, it is often impossible to see such a well unless it happens to be in operation at the time of observation. In previous government publications and other references, no particular mention has been made of this category of tubewell.

though distributary operations data demonstrate conclusively that surface supplies to the tail reach are consistently less in quantity and greater in variability than are deliveries to top-end watercourses. The possibility of such a relationship had been conjectured by several observers. The 1988 Report of the National Commission on Agriculture also specifically recommends incentives to encourage tail-end farmers to use groundwater to "compensate for inequities in the canal water distribution system." As will be discussed later, there appear to be good reasons for the absence of this pattern of tubewell distribution in Lagar command, as well as significant risks in policies that may seek to encourage such a development.

Figure 7.3. Private tubewell density: Lagar Distributary command.

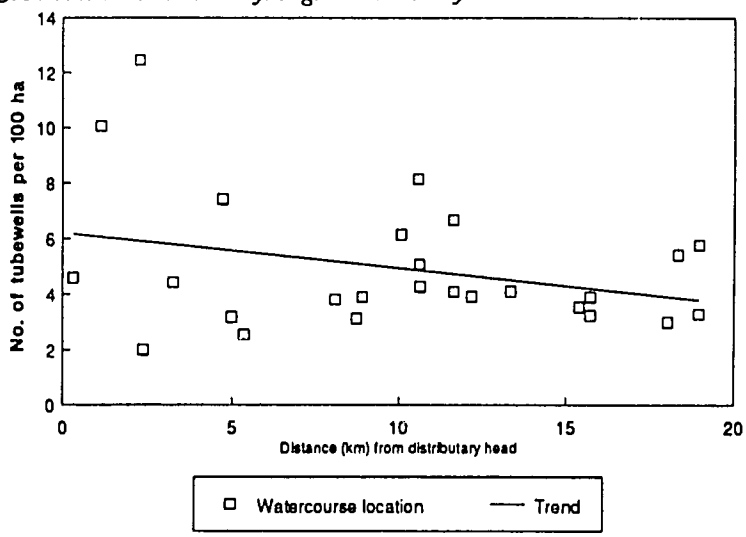
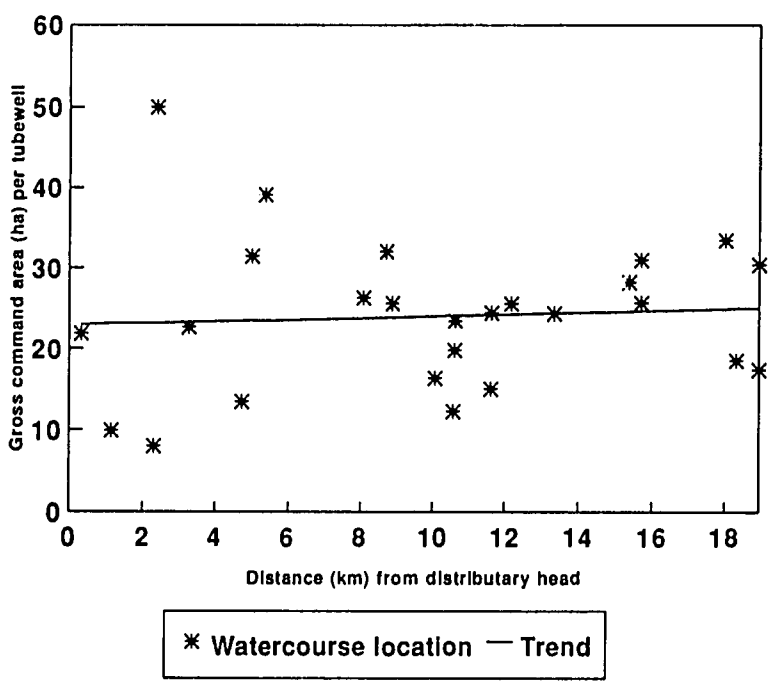


Figure 7.4. Private tubewell distribution: Lagar Distributary command



Twenty-four of the public tubewells included in this study are part of the SCARP I project area, either in Khanqah Dogran or Shahkot Sub-Division. Five of these wells are no longer operational, including two in Khanqah Dogran that have been formally turned off or abandoned as part of the SCARP Transition Pilot Project begun there in 1987. Generally, at least one public tubewell was installed in every Lagar Distributary watercourse command, typically located very near to the outlet so that its discharge could be combined with that of the surface system at the watercourse head for distribution throughout the command. Interesting exceptions to this pattern are found both in Lagar Distributary and in other distributary commands in SCARP I, but they tend to complicate any detailed analysis of present public tubewell operations and water use within a hydrologic unit.

This pattern of layout of the public groundwater irrigation system — the principal objective of which was more to manage the water table than to provide irrigation supplies — was not without significant problems (e.g., those resulting from the mismatch between design watercourse flows and greatly enhanced average watercourse flow conditions). However, the use of the existing surface watercourse system to distribute public tubewell water to farmers meant that the existing equity principle of access to public irrigation water could, by and large, be maintained through the warabandi system, wherein an equal unit of irrigation time is allocated to each unit of irrigable area in the watercourse command. After more than 25 years of farm-level experience with, and accommodation to, the de facto conjunctive operations of public surface and groundwater systems in which the equity principle has been operative, there is substantial concern that equity in access to groundwater will not be sustained as public tubewells are replaced by increased private development of groundwater.

Tubewell Discharge and Installed Capacity

For selected watercourse command areas along Lagar Distributary, more detailed data has been collected on both private and public tubewell discharges, depth to water table, and drawdown. Initial measurements were done by IRI on virtually one-half of the private tubewells in the area, and these have been supplemented by subsequent IIMI field observations and measurements.

Average discharge of private tubewells in Lagar command is about 30 liters per second (l/s) ranging between a low of 8.5 l/s and a high of 53.5 l/s. There is only slight variation and no discernible spatial pattern in these values between watercourse commands. The average discharge value is also basically the same as had been previously reported by IRI, based on their Punjab-wide surveys of private tubewells in the 1970s. Public tubewell discharge ranges between a little more than 9 l/s and nearly 110 l/s, averaging about 57 l/s. This average is considerably below the 85 l/s and 113 l/s design discharge for SCARP I tubewells.

Using the average values to estimate for all operating private and public tubewells in Lagar command, the total installed operational tubewell capacity here is slightly more than 12 cu.m/sec. Public tubewells represent roughly 1.75 cu.m/sec or only about 15 percent of this installed pumping capacity. By contrast, the sanctioned full

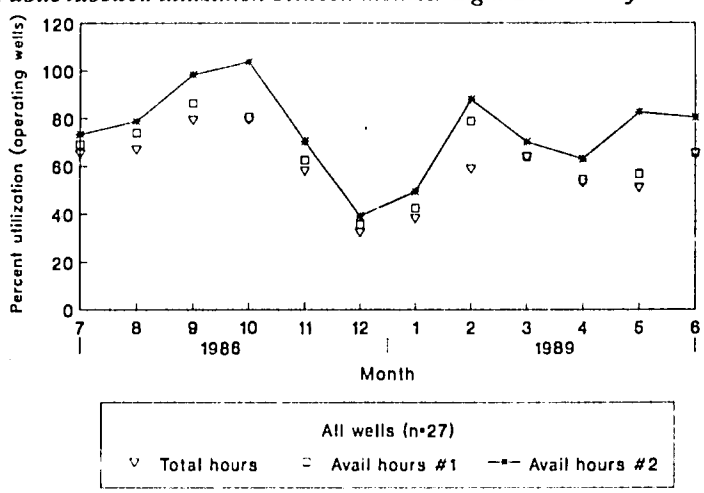
supply discharge for Lagar Distributary is only 1.08 cu.m/sec, less than one-tenth of the current installed tubewell capacity in its command. In reality, of course, the differential in the actual sources of total irrigation water supply is by no means so great, since tubewells, especially private ones, operate in much less of the available time than does the canal system.

THE USAGE OF TUBEWELLS

Public Tubewell Operations

Field measurement and observational data on public tubewell operations in Lagar and Mananwala watercourses for a 12-month period covering mid-1988 to mid-1989, provide considerable insights into operational patterns and problems. A high degree of variability in public tubewell operations between months is very evident (Figure 7.5).[30] Maximum levels of operation were encountered in September and October, undoubtedly reflecting both the overlapping of kharif season and rabi season irrigation demands, especially to finish the rice crop in the former case and to meet pre-sowing irrigation to raise soil moisture to field capacity for wheat in the latter case; these levels of operation also reflected the lower probabilities of significant rainfall in these months when evapotranspiration rates were still relatively high.

Figure 7.5. Public tubewell utilization between months: Lagar Distributary command.



Avail hours #1 = less inop days
Avail hours #2 = less loadshed hrs + #1

[30] Field data have been adjusted as much as possible to reflect accurately the effects of equipment failures both in the tubewells themselves and in the electric meters used to determine operational time, the impact of electric power load shedding, and variable calibration factors resulting from changes in a multitude of environmental conditions (e.g., falling water tables, slow motor deterioration, slow bore failure, meter replacement, motor rewinding, etc.).

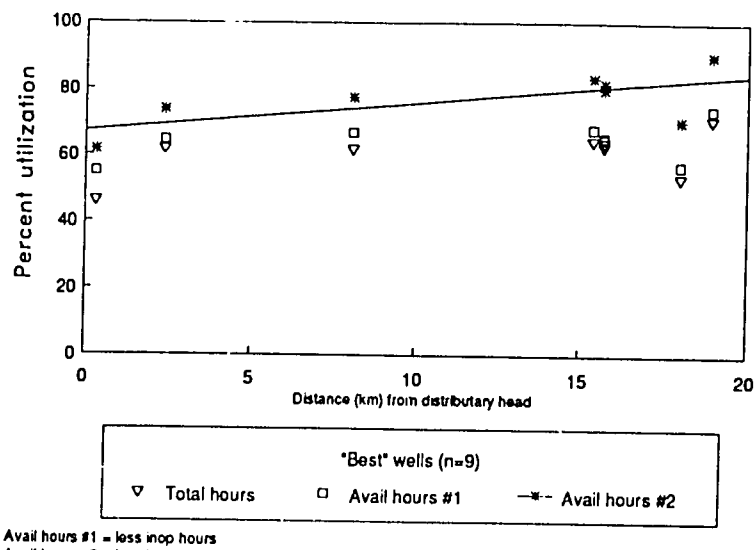
The months of least public tubewell operations were December and January, when they operated less than one-half as much as in the peak months. December and January were also the months when potential evapotranspiration (PET) was lowest. Although most farmers attempt to give the critical first irrigation to rabi wheat in December, usually in the second or third week, the public tubewell system is not "pushed" to deliver water so long as the surface irrigation system is effectively operational and some rainfall has occurred.

Such a conjunctive relationship is largely confirmed by conditions observed in February, the third highest month of public tubewell operations measured. In rabi 1988-89, February also coincided with the closure of the canal in Farooqabad Sub-Division for annual maintenance. While PET was still at a low level — calculated at 2.3 mm/day for February 1989 in Lagar command — public tubewell operations were nearly twice those of the preceding two months as farmers sought to give their wheat crops a second irrigation when the surface irrigation system was not functioning.

For the "best" public tubewells in Lagar command (i.e., those that have been inoperable less than one month throughout the year, due to equipment failure), the average annual utilization rate is nearly two-thirds of the available hours. When power system load shedding is accounted for throughout the year, however, the average annual utilization rate rises to three-quarters of the available hours.

When the location of these public tubewells is examined in relation to the distributary system (Figure 7.6), a gradual though distinct trend toward greater public

Figure 7.6. Public tubewell utilization according to location: Lagar Distributary command.



Avail hours #1 = less inop hours
Avail hours #2 = less loadshed hrs + #1

tubewell utilization is evident from head to tail. This trend is strongly associated with the pattern of marked decline in water deliveries by the surface system to outlets from distributary head to tail. Thus far, however, based upon currently available electricity feeder data, it remains unclear whether or not the impact of load shedding schedules has caused a spatial bias in the distribution of public tubewell water within watercourse commands.

Overall there is growing evidence that public tubewells, at least in Lagar command, in fact, constitute a farmer-managed irrigation system. In addition to largely determining their operating hours (e.g., by directly turning public tubewells on and off, or directing the activities of tubewell operators who, without exception, insist they cannot ignore farmer "demands" for fear of retaliation, physical or otherwise), farmers commonly organize to secure the maintenance of public tubewells. Farmers regularly search out the ID tubewell maintenance crews to directly negotiate tubewell repairs, organize transport to move them and their equipment from one site to another, provide meals and other incidentals to crew members, and pool funds to purchase needed parts or to influence key officials. In short, farmers do whatever is necessary to get an inoperable public well functioning again, provided it is still possible to do so.

Private Tubewell Operations

Preliminary analyses of private tubewell operational data in Lagar command reveal their average annual utilization to be about 12 percent. Based upon installed capacities, this means that for the period for which direct comparisons can be made — at this time, only the last half of 1988 — private tubewells pumped about 15 percent more water than did public tubewells. Moreover, the combined pumping of public and private tubewells from the aquifer underlying the command area yielded water supplies (for farmers to irrigate crops throughout the command area) that were slightly more than double the design full supply discharge for Lagar Distributary. This highlights the extremely important role groundwater now plays in the system of irrigated agriculture in Lagar command.

Most importantly, the data show that there are distinct differences between the ways that private electric, diesel, and tractor-powered pumps are used. Electric tubewells operated during nearly 27 percent of the available time, a utilization rate almost 3.5 times greater than for diesel pumps and more than 10 times the rate for tractor-powered pumps. In short, private electric tubewells are used much more intensively than are either diesel or tractor-powered tubewells. As yet, there is insufficient data to draw firm conclusions about the causes of this pattern of private tubewell usage, but field observation and interview information suggest several plausible reasons for it.

There is some evidence that electric tubewells have more owners, or that their ownership is shared more widely than for other tubewell types. Hence, the average command area per private electric tubewell is greater than for other types of wells. Less certain at this time is whether or not electric tubewell owners use more water per unit area, either by planting crops that require more water or by irrigating the same crops with more water.

Electric tubewell owners also apparently sell more water than do other tubewell

owners and they do so at lower costs per hour. Complementary observations suggest that wherever non-well owners have an option to choose between tubewell types when they need to buy water, electric tubewells are more frequently chosen. Many electric tubewell owners pay flat rate power charges which, in fact, is one incentive offered to stimulate further private tubewell development in the SCARP Transition Pilot Project area. Most other electric tubewell owners pay de facto flat rate power charges because their electric meters which were originally calibrated to show correct readings have been tampered with so as to show lower readings. Thus the actual cost of pumping groundwater for electric tubewell owners is a good deal less than the costs encountered by owners of diesel and, especially, tractor-powered tubewells.

Finally, current evidence indicates that private tubewell utilization, especially for the most intensively used types (electric and diesel-powered), is somewhat sensitive to the quality of groundwater being pumped. Private wells that pump good to marginal quality groundwater are worked at least 33 percent more intensively than those where groundwater quality is poor, except in the case of tractor-powered wells. That finding also tends to confirm the observation that tractor-powered wells fill a more site-specific niche in the overall irrigation system, as sources of water to fill recurrent gaps between supplies and demand rather than as farmers' primary sources of irrigation water.

THE QUALITY OF TUBEWELL WATER

Certainly the most unexpected and immediately significant findings thus far from research on tubewells in Lagar Distributary command concern the quality of groundwater being pumped and used for irrigated agriculture. Although the distributary traverses an area that is commonly referred to as a "fresh groundwater area," the majority of tubewells, and notably private tubewells, pump water that is of marginal quality or unfit for agricultural purposes based upon the standards used by the Directorate of Land Reclamation (DLR) of the Punjab Department of Irrigation to classify groundwater quality.[31] This condition is shown for several standard measures of groundwater quality in Figures 7.7 through 7.10.

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[31] Groundwater quality standards for determining the "fitness" of water for agricultural purposes has been a subject of considerable debate in Pakistan for the past three decades. It is fair to say that there is not, as yet, a commonly accepted standard here. In fact, at least three different ranges of values for such measures of water quality as EC, RSC, and SAR have been adopted by the Punjab Department of Agriculture (Soil Fertility Directorate), the Directorate of Land Reclamation (DLR) of the Punjab Department of Irrigation, and the SCARP Monitoring Organization (SMO) of the federal Water and Power Development Authority (SMO) for determining whether or not water is "fit", "marginal," or "unfit" (hazardous) for agricultural purposes. When these classificatory terms are used here, they refer to the standards adopted and used by DLR, which are as follows:

	Fresh	Marginal	Hazardous
EC:	< 1,000	1,000 - 1,500	> 1,500
SAR:	< 1.25	1.25 - 2.50	> 2.50
RSC:	< 10	10 - 15	> 15

Figure 7.7. Private tubewell water quality - EC: Lagar Distributary command.

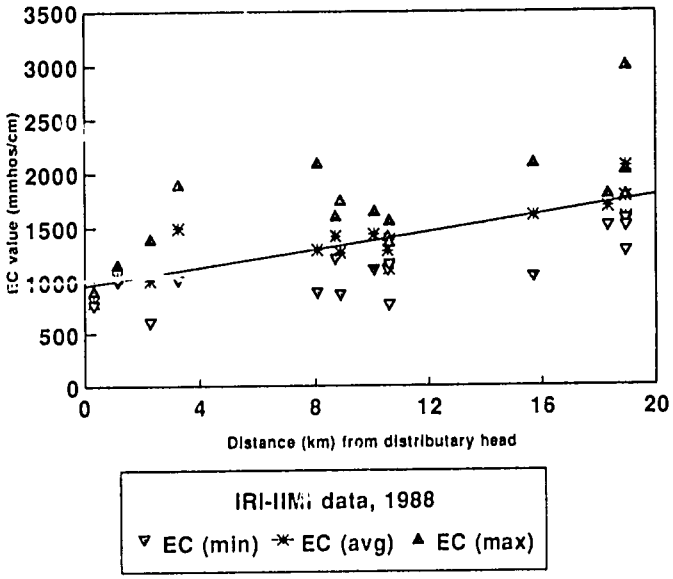


Figure 7.8. Private tubewell water quality - RSC: Lagar Distributary command.

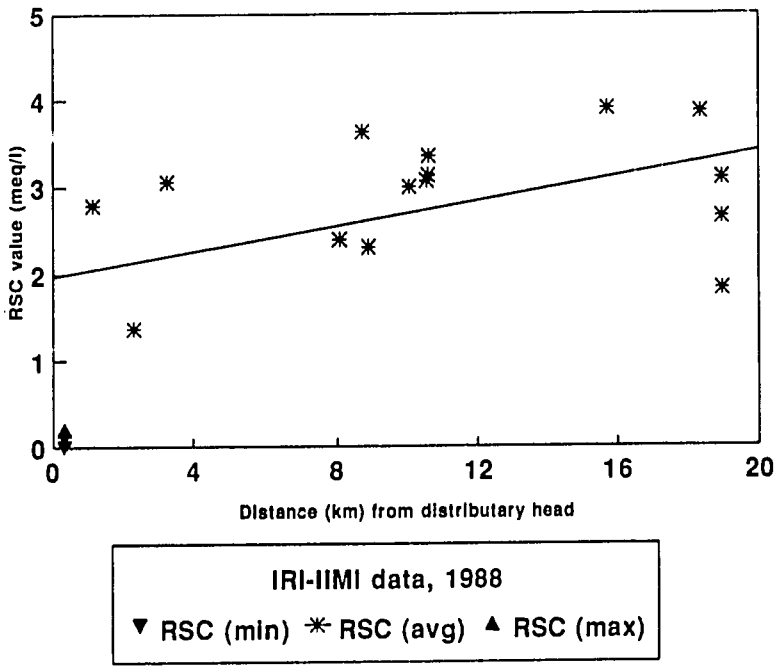


Figure 7.9. Private tubewell water quality - SAR: Lagar Distributary command.

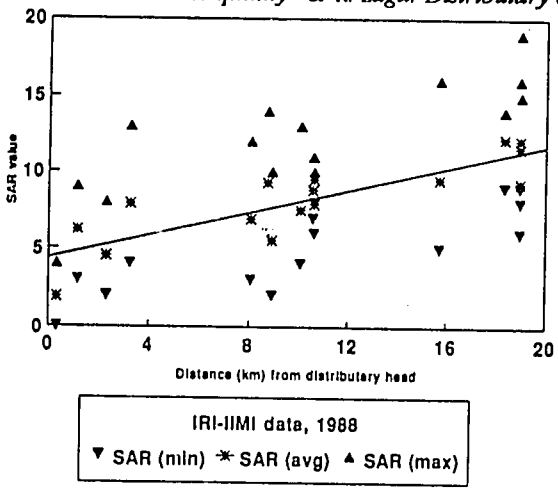
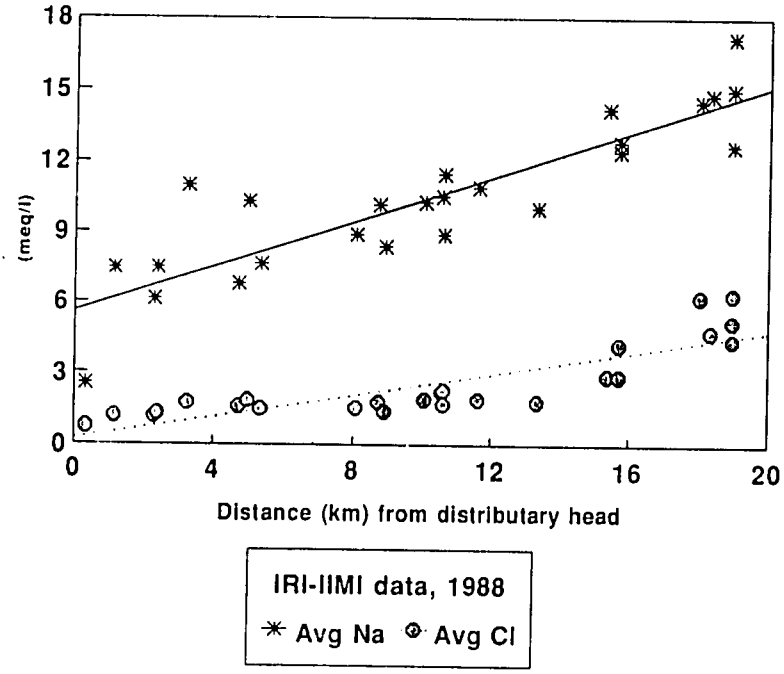


Figure 7.10. Private tubewell water quality: Na & Cl: Lagar Distributary command.

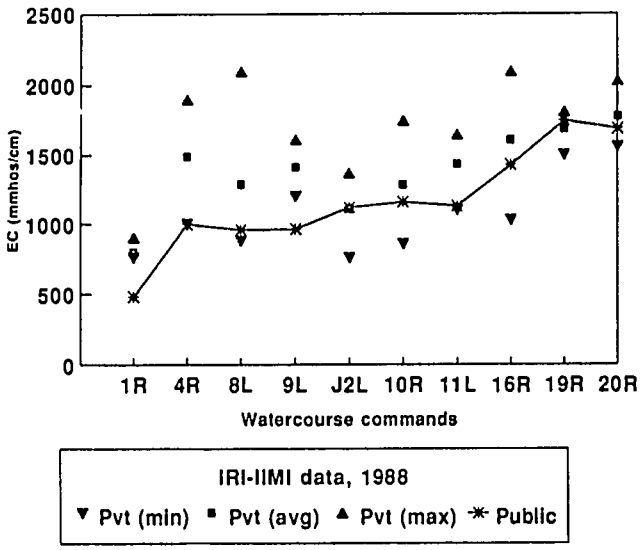


Interestingly, and contrary to a widespread perception of the relative quality of groundwater pumped by public and private tubewells, the average quality of water pumped by shallow private tubewells in different Lagar watercourse commands is not as good as that pumped by the corresponding public tubewells in that command

(Figure 7.11), despite the much deeper bore and greater age of public wells.[32] This finding has particularly important implications for policies and programs that encourage further privatization of groundwater development as an alternative to continuing government operations and maintenance of public tubewells, such as the SCARP Transition Pilot Project currently underway in this locale.

Conventional "wisdom" in Pakistan is that in addition to releasing the government from the heavy burden of increasing O&M costs, the shift from deep public tubewell water to water pumped by shallow private tubewells will bring about an overall improvement in the quality of groundwater used by farmers in any given watercourse command. The evidence from Lagar Distributary command strongly suggests that this may not occur in many cases.

Figure 7.11. Private and public tubewell water quality: Lagar Distributary command.



Most ominously for tail-end farmers already struggling with poor surface water deliveries, there is also a strong trend of deterioration in groundwater quality between the head and the tail of Lagar Distributary, as is evident in Figures 7.7 through 7.10.

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[32] It is not at all clear why the perception that shallow groundwater is "sweeter" (better) than deep groundwater should have gained such widespread currency in Punjab and Pakistan. Analysis of test bore data for Rechna Doab, the area beween Ravi and Chenab rivers, maintained by WAPDA showed that as early as 1960, the majority of test bores sunk within the Doab had confirmed that the quality of shallow groundwater – aquifers tapped by the typical private well – was usually worse than the quality of deeper groundwater tapped by public tubewells.

The deterioration appears to be closely related to how far different watercourse commands along the distributary are from Upper Gugera Branch.[33] The consequence of this condition, of course, is to exacerbate the existing inequity of access to surface water supplies of tail-end farmers. When these farmers compensate for inadequate and unreliable surface water by using pumped groundwater, they must also do so with a poorer quality water than is found in the top-end watercourses of the distributary.

CONJUNCTIVE USE OF SURFACE WATER AND GROUNDWATER

Agency-planned, coordinated or managed conjunctive operations of surface and groundwater irrigation systems do not exist in Punjab, and they have in fact been resisted for a variety of reasons (e.g., the "lack of flexibility and control in the gravity surface system," the absence of reliable information, inadequate communication systems, etc.). Nonetheless, there is substantial evidence that where both systems coexist, farmers have developed their irrigated agriculture based upon the conjunctive use of surface and groundwater supplies. As noted above, in the case of both public and private tubewells, the groundwater irrigation system in Lagar Distributary command is substantially under farmer control and management, albeit in the absence of any apparent overarching institutional arrangements to coordinate operations or to solve problems over extensive areas.

In the present environment, the surface system appears to be essentially a passive source of differential water supplies. Virtually everyone understands that location largely determines the amount of water and degree of service that can be expected from the canal system, and little can be done to physically change one's locational advantage. Moreover, farmers also know that even under the best of all possible operating conditions, it would be impossible for the surface system to supply the amounts of water necessary to sustain the present remunerative cropping patterns that emphasize sugarcane and fodders throughout the year, rice in kharif and wheat in rabi, at annual cropping intensities in excess of 100 percent of the command area.

Thus, the canal system remains the "floor" for contemporary irrigated agriculture in much of Punjab, but it is quite a different floor than what it once was. No longer is

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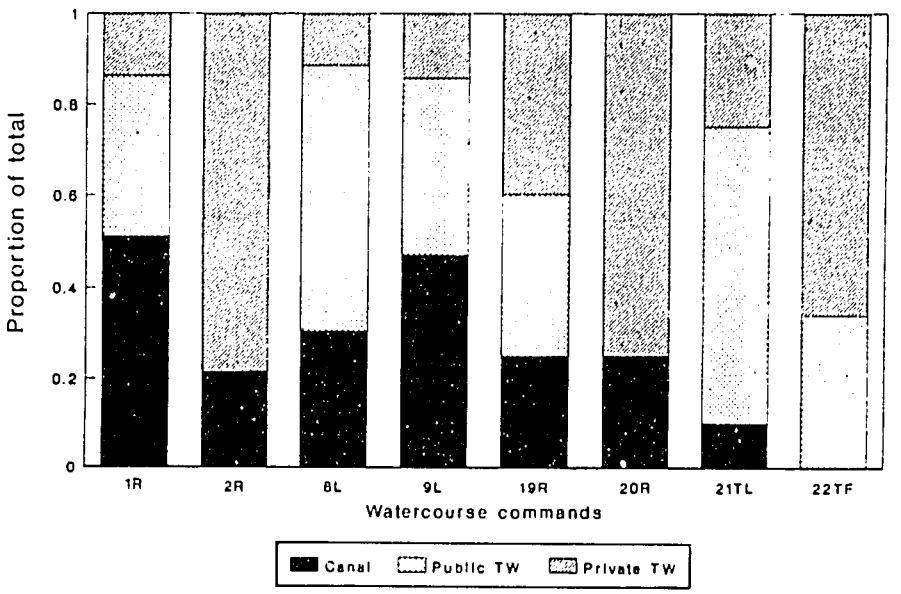
[33] This main canal is never more than 5 or 6 kilometres east of Lagar and it begins to assume an alignment roughly parallel to the distributary about 6 kilometres downstream from its head. The assumed relationship is based upon the observation that the decline of private tubewell water quality for watercourse commands on the southeast side of Lagar (closer to UG Branch) is less rapid than on the northwest side of the distributary. It is also based on the assumption that UG Branch and the QB Link Canal, paralleling it immediately to the east and generally carrying more than 500 cu.m/s, are the primary sources of aquifer recharge in the Lagar command area. A decline in the absolute level of the water table both with increasing distance from UG Branch and proceeding down Lagar Distributary also strongly suggests groundwater movement in this direction.

it the "floor" in the late 19th or early 20th century sense, protecting vast areas from crop failure and consequent famine conditions. In the late 20th century, the canal system has become the "floor" in the sense of a foundation upon which the present agriculture system for much of Punjab is constructed. In this context, it is now the groundwater system of both public and private tubewells which is actively operated and managed to meet crop needs. The result, now clearly discernable in Lagar Distributary command is a number of small-scale, relatively discrete de facto conjunctive operation-and-use environments.

Data now permit an evaluation of irrigation water sources for an entire crop season for several different watercourse commands located along Lagar Distributary (Figure 7.12). They demonstrate that from head to tail, canal water supplies provide a decreasing fraction of the total water available to, and used by, farmers. Even in the most locationally advantaged watercourse command, 1R, surface water provided only slightly more than 50 percent of the total amount of irrigation water used by all farmers. In the two most distant watercourse commands served by Lagar, surface water constituted no more than 10 percent of all irrigation water used in the season.[34]

Figure 7.12. Irrigation water sources: Rabi 1988-89: Lagar Distributary command.

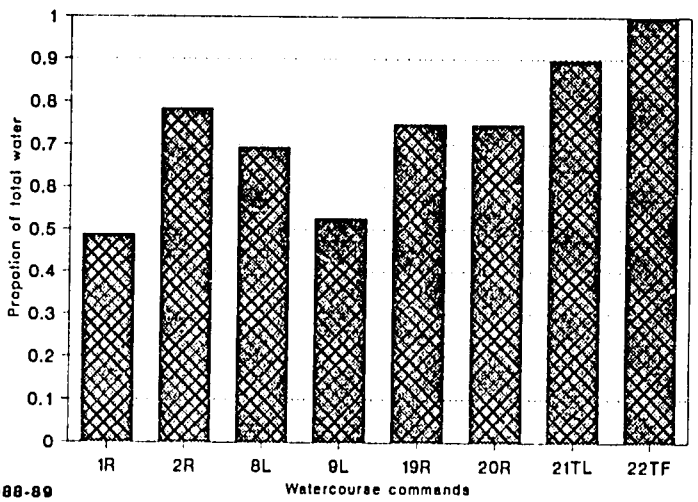


[34] The range of variation of irrigation water sources used by individual farmers within different Lagar watercourse commands is not yet known.

Conversely (Figure 7.13), there is an equally strong trend of increased reliance upon tubewells, differentially public and private, for irrigation supplies from head to tail along the distributary. In one tail watercourse command, only pumped groundwater and rainfall sustain the agricultural system, and a very large fraction of the former (Figure 7.12) is derived from private tubewells. The proportion of irrigation water contributed by the groundwater system elsewhere in the tail is also very large in comparison to proportions in other locations along Lagar, with one significant exception.

Watercourse command 2R is located advantageously in relation to the head of the surface system. It also has the advantage of a paved road that bisects the command, and it contains a large expanse of formerly undeveloped land that was too high to be served by the canal system. Over the past ten years or so, there has been entrepreneurial development of these lands by leaseholders using water from tubewells that they have installed for intensive cultivation of horticultural crops for sale to nearby urban markets. Nearly 80 percent of the irrigation water used in this command in rabi 1988-89 to sustain two successive vegetable crops came from private tubewells, the largest concentration found in any Lagar watercourse, all but one of which was in place before the public tubewell was disconnected as part of the SCARP Transition Pilot Project. In this watercourse command, conjunctive use means an interdependent coexistence of systems where tubewells always supply water to farmland that cannot be served by the surface system, and sometimes supply water elsewhere in the command area to supplement shortfalls in surface supplies.

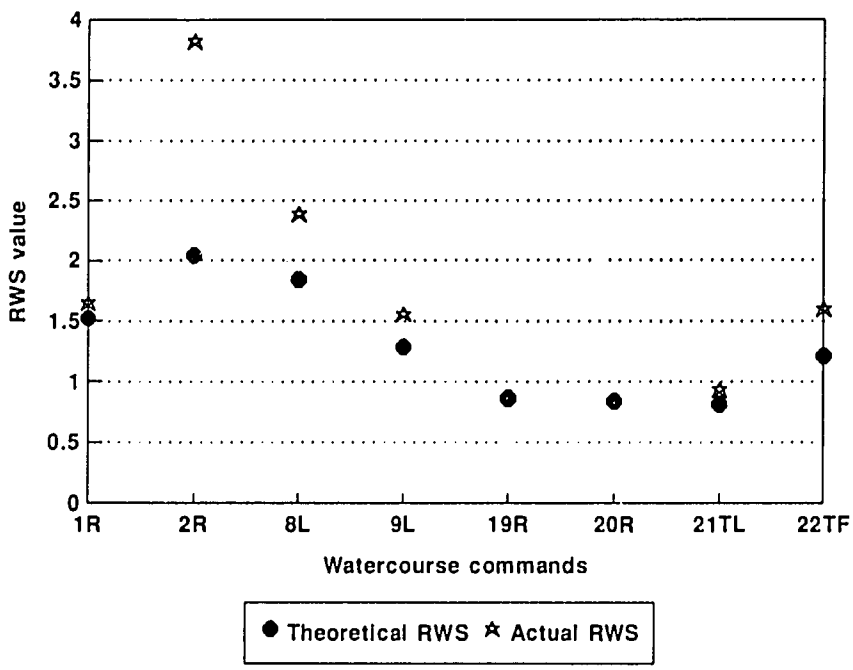
Figure 7.13. Proportion of irrigation water contributed by tubewells: Lagar Distributary command.



Private tubewells supply very nearly the same proportion of water for irrigated agriculture in watercourse 20R, virtually at the tail of the canal, as at 2R, but the crops grown there are markedly different. Wheat, not vegetables, is overwhelmingly the rabi crop, along with a small amount of fodder. The public tubewell in this command too was abandoned by the ID several years ago because it was considered irreparable. Farmers here continue to complain bitterly about its loss, because they claim that the water it pumped was of a much better quality than can be obtained now from their shallow tubewells. In this watercourse command the surface system is much more significant than the mere one-quarter of irrigation water that it supplies would indicate. Conjunctive use here commonly means interpenetration, mixing even small quantities of surface water with pumped groundwater to reduce the impact upon crops of the higher salinity of the latter.

The resulting relative water supply (RWS) conditions for different patterns of conjunctive use of surface and groundwater systems in these watercourse commands (Figure 7.14) suggest that in the aggregate, farmers aim for a relatively comfortable condition between 1.5 and 2, whether at the head of the distributary or the tail. While this is consistent with findings in irrigated agriculture systems elsewhere in South and Southeast Asia, these results still need to be considered as tentative and approached

Figure 7.14. Relative water supply: Rabi 1988-89: Lagar Distributary command.



with some caution.[35] Nevertheless, the strikingly similar RWS values for three Lagar watercourse commands, 1R, 9L and 22TF (head, middle and tail, respectively) are noteworthy.

At the tail, irrigation water is solely from tubewells, two-thirds of which is pumped by the private sector. In both 1R and 9L, only about 15 percent of all irrigation water is from private tubewells, and the public irrigation system — canal plus tubewell — supplies virtually all other irrigation water. This suggests that even when the total irrigation environment of surface and groundwater systems is evaluated, there remains substantial inequity (by a factor of 4 to 5) between tail-end and head-end areas in terms of access to the publicly provided water resource.

CONSEQUENCES: POLICY IMPLICATIONS AND OPTIONS

Enough is now known from IIMI's research on groundwater and surface irrigation in Farooqabad Sub-Division of the Lower Chenab Canal system to permit an initial consideration of some management options that have potential to enhance overall system performance, and to permit identification of several issues with significant implications for irrigation sector policies. This paper concludes by beginning that process.

Management Potentials

Moving from an environment of many separate de facto conjunctive use operations to a more interactive and coordinated conjunctive management of surface water and groundwater systems is likely to be a lengthy and difficult effort. Nevertheless, there exist some apparent starting points for the process, beginning with two periods of the year when it is essential that public tubewells operate at their maximum capabilities to compensate for known, or very likely, disruptions in surface water supplies.

Although efforts are made to schedule the annual closure for canal maintenance in rabi, it does not necessarily mean that during the months of minimum potential evapotranspiration (PET) most crops will not require an irrigation during this period, particularly given that closure periods extend for more than three weeks over many

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[35] Overall, the RWS values presented here are approximate in the absence of other critical or more reliable data. In calculating RWS for the 1988-89 rabi season, the official calendar season (15 October through 14 April) was used; irrigated area data were from official records (there is some reason to be circumspect about their accuracy) and area planted to different crops was unknown; adjustments could not be made for water distribution inefficiencies and losses beyond the watercourse head or the tubewell discharge pipe; rainfall was assumed to be equally distributed throughout the distributary command (although observation indicates this is often not the case). Thus, for example, the true RWS value for 2R is likely to be rather lower, since about half the area is planted to two crops that span the rabi season and another two to four weeks on either side of it.

distributary commands and that this is the season of maximum planted area. Insofar as the annual closure is scheduled in advance by the Irrigation Department (ID) after consultations with WAPDA and the Agriculture Department, it ought to be a relatively simple matter for the ID to ensure that wherever public tubewells supply irrigation water, they are in the best possible operating condition. In short, a modest effort to target the expenditure of maintenance funds is more likely to achieve system performance improvement than the ad hoc procedures currently being followed. Similarly, since all public tubewells are electric-powered, WAPDA should target feeder line O&M to public tubewells for the same period. Also, if load shedding operations are mandated, they ought to be staggered or rotated so that the same wells are not turned off for the same period every day, every week, which is the current pattern for every WAPDA-mandated load shedding schedule.

The second period of opportunity occurs during kharif and, although perhaps less predictable, it, too, is well-known. During the monsoon or rainy season portion of kharif, canal flows are commonly reduced in response to river conditions to prevent heavy silt accumulations in the main and secondary channels. July, August and early September are the times when these actions occur, a period when crop water requirements are below peak levels but are still very high. Again, added stress often is placed upon public tubewells to make up surface system short-falls, and an organized effort to ensure their continued operations is especially likely to benefit the agricultural system. There is no evidence that this is currently done, nor any suggestion that it could not be done.

With respect to the surface irrigation system, there is a complement to the options that focus on the public tubewell system. In May and June, especially (the months of maximum temperatures throughout the Indus Basin), WAPDA's electric supply system is stressed beyond capacity. All available evidence confirms that this condition will worsen over the next few years before it improves. This is a period of maximum scheduled load shedding for the power supply system. Therefore, it is logical that at this time additional emphasis should be placed upon maximizing efficient canal system operations in order to compensate as much as possible for disruptions in the operations of public tubewells and electric-powered private tubewells. Canal operations data for Lagar Distributary in kharif 1988 demonstrated that sustained levels of near-design discharges in May are possible, and one consequence then was a minimum level of head to tail inequity in surface water supplies. This could also take the form of increased maintenance patrolling, to ensure that weak points in the system are promptly reinforced before breaches occur, and to discourage, if not completely prevent, water theft. The more frequent presence of canal operations officers in the field at this time is an obvious adjunct to such efforts.

Irrigation Sector Policy Implications

With respect to efforts to develop an effective program of turnover of public tubewells to the private sector, there are several reasons to reconsider the current strategy embodied within the SCARP Transition Pilot Project. Most worrisome is the prospect

that the replacement of public tubewells pumping from deeper aquifers by private tubewells pumping from shallow aquifers will result in an overall decline in the quality of irrigation water available in the current agricultural system. The impact of such a development, particularly upon the sustainability of irrigated agriculture, can only be guessed at, but it is highly unlikely to be positive.

Also of concern is evidence that private electric tubewells are used much more intensively than other private tubewells whereas, until now, a 12 percent utilization factor was assumed to be applicable regardless of power source. A turnover strategy which incorporates incentives and subsidies that directly encourage an increase in the numbers of electric tubewells seems certain to add greater stress than anticipated to an already overloaded power supply system.

In fact, tubewell densities throughout Lagar Distributary command strongly suggest that special incentives and subsidies to encourage private tubewell development are simply not necessary. Indeed, it is likely that in many areas, the installed capacity of private tubewells is already more than sufficient to compensate for the termination capacities of public wells so long as equity considerations are not an issue.

Public tubewells, however, are still supplying substantial proportions of the total amount of irrigation water that farmers use in a large number of locations. This is done under a long-accepted equity principle. Terminating public tubewells will therefore almost certainly have important equity implications for many farmers, especially for those without ready access to private water supplies. The absence of a significant effort to address this issue in the current pilot turnover strategy is cause for genuine concern.

Calls for policies that would encourage further private tubewell development in the tail-end areas of distributaries, as a way of compensating for inequities in the surface water distribution system, may not be warranted if the spatial pattern of water quality deterioration for private tubewells pumping from shallow groundwater aquifers in Lagar command is a more widespread phenomenon. At the very least there is an urgent need for a province-wide study in Punjab to evaluate shallow groundwater aquifer conditions and behavior in greater detail. Sources and rates of recharge, in particular, need to be accurately determined so that while they can be protected, water table drawdown from tubewell operations can also be sensibly regulated.

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CHAPTER 8

Salinity in Punjab Watercourse Commands and Irrigation System Operations

Jacob W. Kijne and Edward J. Vander Velde

FOREWORD

FIELD RESEARCH SPECIFIC to "Managing Irrigation Systems to Minimize Waterlogging and Salinity Problems," an IIMI Pakistan project financially supported by the Government of the Netherlands, was formally initiated in 1989. An initial phase of detailed field research in selected canal system commands in Punjab and Sindh provinces will be followed by a second phase in which recommended management interventions are field-tested in action during the five-year life of the project. In Punjab, it has been possible to organize and implement a substantial portion of the primary research phase in conjunction with the field activities of other IIMI Pakistan projects, facilitating the sharing and wider use of more generic irrigation system data and information resources, and avoiding costly duplication of effort. Most importantly, it has made possible the integration of a range of primary data, analyses, and initial findings on irrigation system operations and performance across distributary canal commands, the large hydraulic units which constitute the Indus Basin irrigated agriculture system. This paper reports the preliminary results of that joint research effort.

Interestingly, while the technical objectives in the project paper call, inter alia, for reliable field data to quantify the relative contributions of the several possible sources of waterlogging, no such requirement for primary field data to quantify the sources of (secondary) salinity was included in the original project design. Possibly the effects of waterlogging were assumed to be far more severe than those of salinity on productivity of irrigated agriculture in Pakistan. More likely, there was inadequate recognition of the degree to which such salinity in Punjab is now disassociated from waterlogging. Also, in Pakistan generally and the Punjab especially, the absolute incidence of waterlogging has been greatly reduced, first by the installation and operation of public sector deep ("drainage") tubewells through the Salinity Control and Reclamation Project (SCARP) programs and, more recently, as a consequence of the rapidly growing exploitation of groundwater for irrigation by private sector shallow tubewells, which are now estimated to exceed 280,000 units.

The project paper also specified that IIMI's research will focus on "the irrigation and drainage environment conditions of incipient (and, as yet, not apparent) waterlogging and salinity problems," and two field research locales were anticipated for this purpose; one each in Punjab and Sindh.[36]

In Punjab, where IIMI-Pakistan was already conducting research on canal system performance and constraints on irrigated agriculture below the outlet in selected distributary commands of the Lower Chenab Canal (LCC) system, the choice of field-research sites was not based on any knowledge of incipient conditions of salinity or waterlogging. Indeed, in early 1989, conventional wisdom in Water and Power Development Authority (WAPDA) and other irrigation and agricultural agencies was that groundwater in Farooqabad Sub-Division in the Upper Gugera Branch command was generally of good quality ("sweet" or "fresh"), but moderately to strongly saline throughout much of Bhagat Sub-Division in the Lower Gugera Branch command. Subsequent IIMI field surveys confirmed that water tables were commonly more than three meters (3m) below the soil surface in both locales, and standing water in low areas around Pir Mahal was the result of surface ponding rather than high water tables.

These conditions did not, however, invalidate either command area within the LCC system being appropriate sites in which to address key salinity issues. Preliminary analyses of various field data being collected for IIMI's research on the conjunctive management of surface water and groundwater systems were already beginning to reveal unrecognized, even largely unanticipated, salinity problems, first in Farooqabad Sub-Division and later in Bhagat Sub-Division. The work of R. L. Johnson, an IIMI research fellow who conducted a study of latent groundwater demand in part of Farooqabad Sub-Division, was of particular importance in this respect.[37]

This report is based upon primary field data collected in watercourse and distributary canal command areas of both research locales — Farooqabad and Bhagat Sub-Divisions — without a strict separation between the two sites. Our rationale for this approach is that, in terms of tubewell water quality and the problems of secondary salinization, both areas present a very similar picture. Although a more detailed understanding is currently available for conditions in Farooqabad, because data collection began earlier there than in Bhagat, enough is already now known about the widespread and increasing reliance in Bhagat upon tubewells that are pumping marginal or poor quality water to conclude that our findings have more than localized implications. Moreover, the factors that we hypothesize are causing or intensifying secondary salinization problems which will require new, environmentally sophisti-

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[36] Because of serious law and order problems throughout much of rural Sindh since September 1989, it has not been possible to initiate the substantial field-research program that has been planned there. However, in collaboration with the Soil Survey of Pakistan, a reconnaissance survey of soil conditions in the command of the Hasan Ali Branch canal in the Fuleli Canal system (near Hyderabad) has been underway since March 1990, and the tabulation of official data with irrigation and agriculture agencies was begun in early July.

[37] See Robert L. Johnson, *Latent Groundwater Demand in Pakistan's Punjab: Theory and Applications*, (Ph.D. dissertation, Ithaca, NewYork: Cornell University, 1991) for details of this research.

cated, often linked and sustained irrigation management interventions at main as well as secondary system level if the threat to the sustainability of irrigated agriculture in large areas of the Indus Basin is to be reduced. Nonetheless we are aware that the management interventions required are unlikely to be the same everywhere.

As the root cause of the problems, we identify the growing imbalance between the availability of good quality canal water and of poor quality groundwater as one proceeds down the system, the distributary, and the watercourse. The solution therefore depends on the possibility of ending or at least mitigating the inequity of distribution of the two sources of irrigation water. Some of the distribution-related issues and irrigation management implications are tentatively addressed in the final portion of our discussion.

THE STUDY AREAS: AN INTRODUCTION TO THE IRRIGATION ENVIRONMENT

Primary measurement data have been collected by IIMI and its research collaborators for a large number of sample watercourses, off-taking from Lagar and Mananwala distributaries in Farooqabad Sub-Division, Upper Gugera Branch, and from Pir Mahal and Khikhi distributaries in Bhagat Sub-Division, Lower Gugera Branch. These data have also been used in one or more of IIMI-Pakistan's other research projects (e.g., distributary-level canal performance and conjunctive management of groundwater and surface irrigation systems). The data now available cover a wide range and include spatial and temporal variability in discharges in the canal system, public and private tubewell operations and the extent of groundwater usage at watercourse and farm-level, to seasonal crop surveys, and the water and salt balances of crop root zones in selected areas. In some cases, data are available from as far back as August 1987; in other instances (e.g., for water and salt balances), data availability is only since kharif 1989.

Our discussion of the incidence of salinity is based largely upon primary data collected in the command areas of two watercourses served by Mananwala Distributary and two off-taking from Pir Mahal Distributary. Mananwala Distributary off-takes from Upper Gugera Branch in Farooqabad Sub-Division, Upper Gugera Division, about 68 km downstream from Khanki Barrage, the headworks of the Lower Chenab canal LCC system (Figure 8.1). Pir Mahal Distributary off-takes from Lower Gugera Branch in Bhagat Sub-Division, Lower Gugera Division, more than 200 km further downstream. Both are in the LCC East Circle, and the entire LCC system comprises the Faisalabad Zone of the Punjab Irrigation Department.

Mananwala Distributary is 45 km in length and its design discharge is 5.2 cu.m. It supplies 125 sanctioned outlets (either directly or from three minors) and serves a cultivable command area (CCA) of 27,064 ha. The average sanctioned discharge of its outlets is 30 l/s. The distributary was designed for two levels of cropping intensity. This means that some outlets, those serving 50 percent intensity command areas, have a design water allocation of 1 l/s per 7.5 ha, whereas others have 75 percent intensity

service areas with a slightly more generous water allocation standard of 1 l/s per 5 ha. In size and service area, Mananwala is a fairly typical distributary in the LCC system.

The first sample watercourse is located at a reduced distance (RD) of 71,683 ft (henceforth RD 71) and the other is at the tail, at RD 143,850 ft (RD 143). RD 71 is situated in approximately the middle reach of the Mananwala Distributary. It has a cultivable command area (CCA) of 288 ha, and a watercourse discharge of 38 l/s. The service area is split in two by a road, and only the northern area, with a CCA of 187 ha, was studied. A deep public (SCARP I) tubewell discharges groundwater into the main, lined watercourse where it is mixed with canal water in a ratio of about 2 to 1. In addition, there are 18 shallow private tubewells operational in the command area.

RD 143 is located at the tail of Mananwala Distributary and has a CCA of 87 ha. Canal water rarely reaches the outlet for RD 143, and then only during periods when cultivators' irrigation requirements are low (e.g., between the seasons or occasionally after a heavy monsoon shower). One SCARP tubewell provides most of the water for irrigated agriculture in the service area, although there are four private tubewells operational here and others under development.

At Bhagat Head regulator, Lower Gugera Branch canal is divided into four distributaries, one of which is Pir Mahal. This canal is 47.5 km long and has a design discharge of 4.67 cu.m for a CCA of 14,891 ha. Pir Mahal directly supplies 50 sanctioned outlets and 40 others off-take from its four minors. The average design discharge of these outlets is 35 l/s. The distributary was designed as a 75 percent intensity channel, with a seasonal cropping ratio between kharif and rabi seasons of 1:2 in its service area.

Watercourses selected for the study of water and salt balances in Pir Mahal command are situated at RD 89 and RD 133, in the middle and tail reaches of the distributary, respectively. The CCA of outlet RD 89 is 173 ha, and the design discharge of the watercourse 46 l/s; for outlet RD 133, these values are 220 ha and 44 l/s, respectively. The amount of canal water that usually reaches the head of RD 133 is insufficient, however, and farmers can irrigate only those fields which are close to the watercourse *mogha*. Consequently, large portions of the command area of RD 133 are completely dependent on irrigation water supplies from tubewells.

A few public tubewells were installed in the tail watercourse commands of Pir Mahal Distributary and Junejwala Minor between 1975 and 1977. These were among the 101 tubewells installed under the Shorkot Kamalia Pilot Project (SKPP) programme as part of an accelerated effort for controlling waterlogging and salinity in the lower Rechna Doab. Here, priority was given to areas with fresh groundwater where the tubewells would serve the double purpose of providing drainage and supplementing irrigation supplies. Tubewell development under this programme continued in the area until 1985.

Contrary to the general perception, private tubewell development has been almost as active in the service area of Pir Mahal Distributary over the past 3-4 years as it has been in Mananwala Distributary command. For example, a tubewell census completed by IIMI in mid-1990 in the 23 outlet commands of Junejwala Minor, Pir Mahal's largest off-taking distributary, revealed the surprising average private tubewell density of more than 7 per 100 ha.

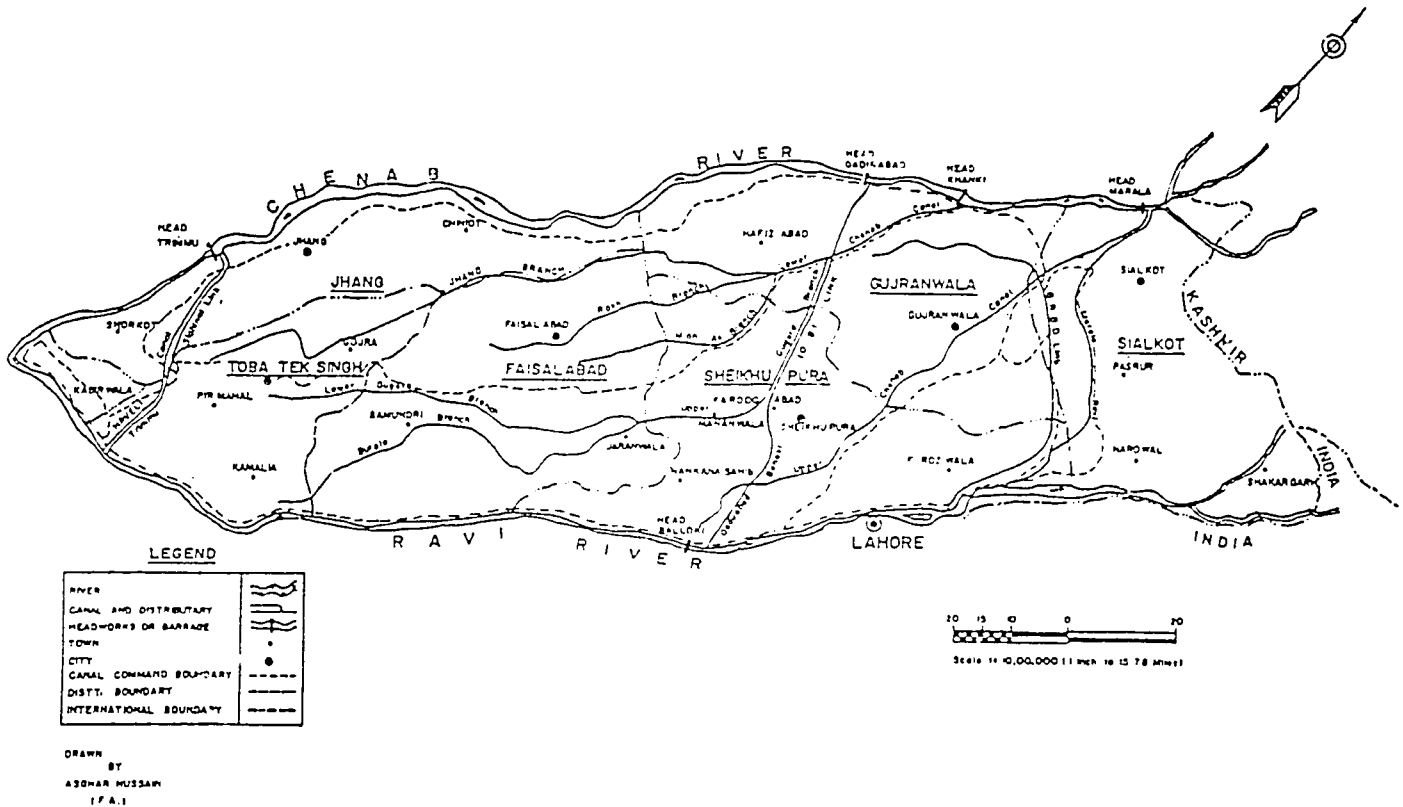


Figure 8.1. Rechna Doab, Punjab, Pakistan.

The service areas of the seven distributaries that constitute Farooqabad Sub-Division, including Mananwala, are wholly within the Punjab rice-wheat agroecological zone. Rice, especially the high-value basmati variety, is the predominant crop in this region during kharif wherever irrigation water supplies are sufficient, while wheat is the principal crop during rabi. In addition to these two major crops, sugarcane and various fodders are grown year-round as well as a range of seasonal fruits and vegetables for both cash income and domestic consumption.

The command areas of Pir Mahal and other Bhagat Sub-Division distributaries fall in the transition zone between the rice-wheat agroecological zone and the cotton-wheat belt of Punjab further to the southwest. Here, cotton is more frequently the main crop during kharif season, and wheat predominates in rabi. However, elsewhere rice remains a significant though a more localized crop where water supplies are relatively abundant (parts of Pir Mahal command and elsewhere). As in the Mananwala service area, sugarcane and various fodder crops are also grown throughout the year, the proximity of a large sugar mill in Kamalia stimulating the production of sugarcane in much of the area. Sesame (an oil seed crop) and vegetables are grown throughout the Pir Mahal command area during kharif, and perennial citrus fruits occupy a considerable and still expanding area. In short, the irrigated agriculture system in IIMI's study areas is characterized by a diversity of crops grown and by large acreages devoted to key crops in Pakistan's agricultural economy.

Topographically, the interfluvial region through which the Upper and Lower Gugera Branch canals flow is flat with little natural drainage. It is underlain by a deep, high-yielding unconfined aquifer that is relatively homogeneous and highly anisotropic. Bennett et al. (1967) provide a detailed hydrologic description of the aquifer, giving the mean values of hydraulic conductivities as 1.2E-3 and 1.5E-5 m/s in horizontal and vertical directions, respectively. The much lower vertical transmissivity is due to the presence of clay layers in an otherwise fairly coarse sandy aquifer. The specific yields with the water table in the sand layer and the clay layer are, respectively, 0.15 and 0.06 (ibid.). It is desirable, therefore, to install tubewells so that the screen length will not fall within the thick clay layers.

Historically, following the extensive construction and operation of canals in the Rechna Doab, significant areas began to suffer from both substantial waterlogging (defined as conditions with water tables within five feet of the land's surface) and salinity. By the mid-20th century, the severity and extent of these problems provided the impetus for the first Salinity Control and Reclamation Project (SCARP I), initiated in the central Rechna Doab in 1960, and subsequently for other SCARP and smaller-scale public tubewell deep drainage projects. Today, the depths of water tables in the Mananwala and Pir Mahal commands range between 3 and 8 m, with gradients towards the tail ends of the distributaries. In the Mananwala region, the primary source of aquifer recharge appears to be seepage from two large canals that pass north to south across the head of the Mananwala Distributary (i.e., the Upper Gugera Branch, carrying about 180 cu.m in this reach, and the Qadirabad-Balloki Link Canal, which carries around 540 cu.m). Recharge to the groundwater in the area of the Pir Mahal Distributary is probably in large measure from the Ravi River, which flows at a distance of only 12 km from some parts of the downstream half of the distributary.

According to the Soil Survey of Pakistan (Bashir Choudhri et al. 1978), most of the salinity in Punjab is ancient, produced as the result of soil-forming processes over thousands of years, greatly predating the rise in water tables associated with the introduction of canal irrigation. Saline patches were recognized as occurring within good land in an intricate spatial pattern when lands were being developed for irrigation. Although larger saline tracts could be, and were, excluded from design canal command areas, the inclusion of smaller patches of salinity within larger extents of good soils was inevitable. Indeed, some of them were subsequently reclaimed, but in other areas reclamation attempts were far less successful.

Conventional wisdom in Pakistan brackets waterlogging and salinity as the "twin menaces" of irrigated agriculture in the country. One is almost preconditioned to assume, therefore, that with the reduction of waterlogging in large parts of the country, (especially in Punjab, through the extensive development and operation of SCARP tubewells, followed more recently by private tubewells) the problem of salinity has largely been solved as well. But as early as 1978, the Survey of Pakistan warned that this was not the case:

> The secondary salinity, which is of much greater concern than that akin to waterlogging, is the build-up of high sodicity in first-rate, non-saline agricultural land caused by irrigation with low-quality tubewell waters. This type of salinity was introduced with (the) accelerated use of groundwater. The symptoms of the sodicity of soils are widespread, as observed from hardening of topsoil, decrease in rate of infiltration and inadequate seed germination, especially of alkali-sensitive crops. This mode of salinization is treacherous, as it operates insidiously and the farmers, due to (the) slow rate of soil deterioration, become aware of the problem (only) after considerable damage has been done (ibid.).

Much of what we report in the following discussion of IIMI's initial research findings in Punjab concerning irrigation management interventions for the control of salinity, and our analysis and interpretation of them, reinforces and substantiates this early, perceptive observation.

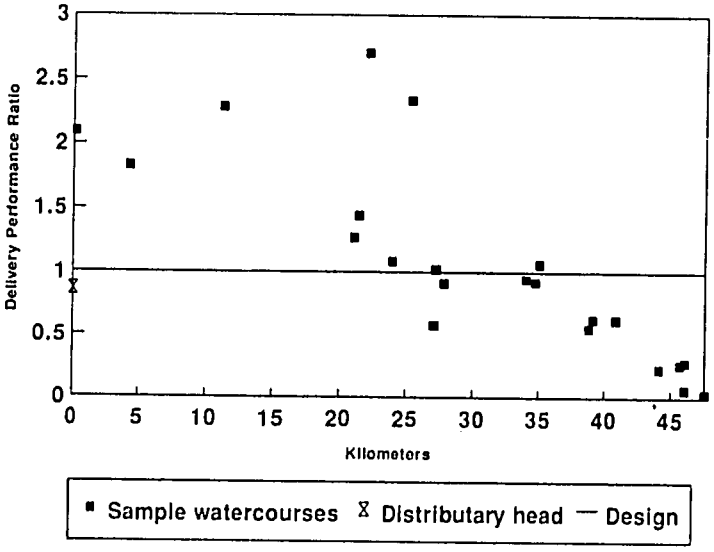
DISTRIBUTION OF WATER SUPPLIES: SURFACE IRRIGATION SYSTEMS

The initial findings of IIMI Pakistan research on the operations and performance of distributary channels in the LCC system of Punjab have been extensively reported elsewhere (Vander Velde and Bhutta 1989; Bhutta 1990; Vander Velde 1990). Therefore, only a brief overview and update are required here.

Analysis of primary measurement and observational data collected through monitoring activities on selected distributaries in both Farooqabad and Bhagat Sub-Divisions has demonstrated that the long-standing system performance objective of equity in surface-water distribution is now rarely achieved and almost never sustained at the secondary canal level. Outlets in the tail reaches of distributaries seldom obtain more than a fraction of their design or sanctioned discharge at the watercourse head,

in contrast to outlets in the upper reaches which commonly receive substantially more than their design discharge.[38] This pattern has been observed, for example, for Pir Mahal Distributary (Figure 8.2), and it is clear that consistently low levels of maintenance of distributary channels are one primary cause. The consequence is that farmers in the command areas of tail watercourses experience, on average, less than one-fifth of the access to surface water supplies that farmers served by watercourses in the head reach of the distributary enjoy (Figure 8.3).

Figure 8.2. Pir Mahal Distributary: Water distribution equity.

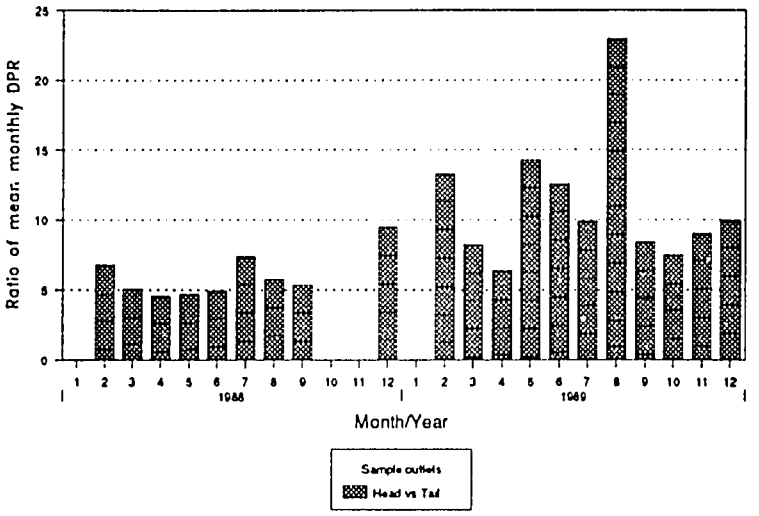


Bhagat Sub-Division

When the discharge entering the distributary head falls below 70 percent of design, an occurrence observed in some LCC system distributaries for as much as one-third of the annually available operational days (Bhutta 1990), water supplies to tail outlets simply collapse, and farmers there receive no water from the canal at all. Canal operations in the Bhagat Sub-Division effectively illustrate the case. There, surface water supplies delivered by Lower Gugera Branch to the tail of the main system are usually insufficient for all six distributaries to operate simultaneously at full supply level. An inter-distributary program of rotational operations is therefore followed for

[38] The measure used here to describe water distribution equity among or between outlets along a distributary is *Delivery Performance Ratio* (DPR). The DPR is the ratio of actual discharge received at the outlet to its design or sanctioned discharge.

Figure 8.3. Pir Mahal Distributary: Equity between sample outlets



No ratio available for Oct.-Nov.,1988
as floods closed the tail outlets

much of the year at Bhagat Head. Data obtained for distributary-head conditions here over several months in 1990 reveal significant inconsistencies in the equitable implementation of scheduled rotational operations (Figure 8.4).[39] In particular, Pir Mahal Distributary is operated at less than 70 percent full design supply for a disproportionate amount of time, contrasting dramatically with the frequency with which Khikhi and Dabanwala distributaries are operated in excess of 100 percent of design full supply discharge.

It must be said that, heavy silt accumulations and serious embankment erosion in Pir Mahal Distributary, especially in its head reach, due to deferred or neglected channel maintenance, preclude its operation at design full supply discharge for sustained periods of time, in any case. These physical conditions have also necessitated the adoption of a program of internal rotational operations between the main channel tail reach and its off-taking minors. One consequence of the resulting pattern of canal operations is that the frequency of days without canal water at the heads of watercourses in Pir Mahal command increases markedly in the tail reach of the distributary (Figure 8.5). These farmers are without surface water supplies for more than 50 percent of the time during extended periods throughout the year.

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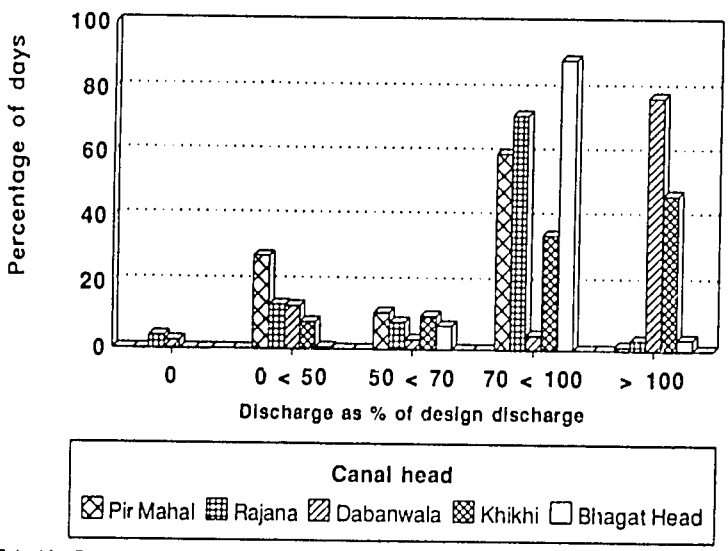
[39] Telog automatic stage recording data loggers were installed at each of the four distributary heads, and they have been operational since the resumption of Lower Gugera Branch canal operations following the 1990 annual maintenance closure period.

Even when distributary head discharge conditions are relatively steady at or near design full supply level, tail watercourse commands are often deprived of even modest surface water supplies by many large and small quasi-legal and illegal interventions upstream to obtain additional canal water. This situation has been regularly observed over the past three years in Mananwala Distributary command. Figures 8.6 and 8.7 show the pattern of water distribution to groups of sample outlet at head, middle, and tail locations in terms of weekly mean DPR for every other week over a twelve-week period marking the onset of the 1990 kharif season. From mid-May on, most tail outlets received no water at all, marking the onset of kharif rice cultivation activities in extensive areas of the upper two-thirds of Mananwala command and the resumption of illicit irrigation operations there to sustain the rice crop through numerous embankment "punctures," syphons, and irregular pipe outlets.

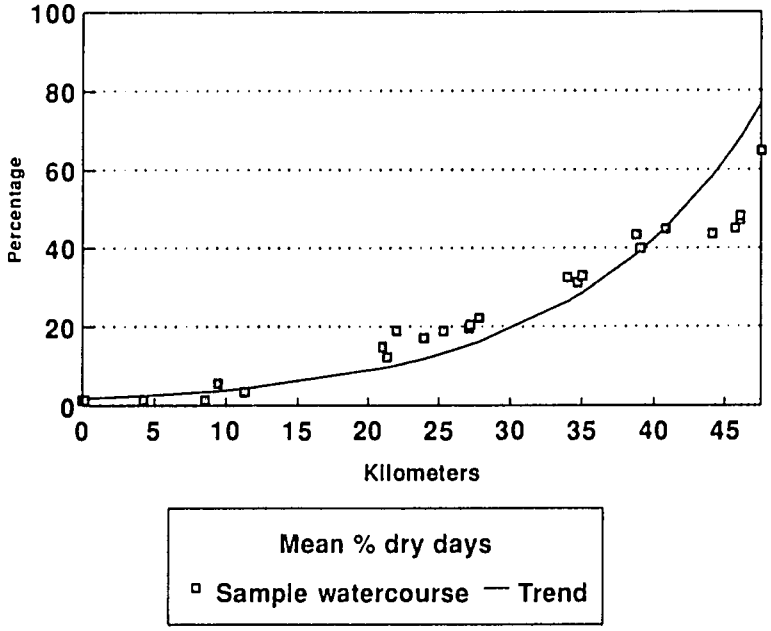
Figure 8.4. Bhagat Head rotational operations: Equity between distributaries.



Feb. 14 - Sept. 11, 1990 (n = 210 days)

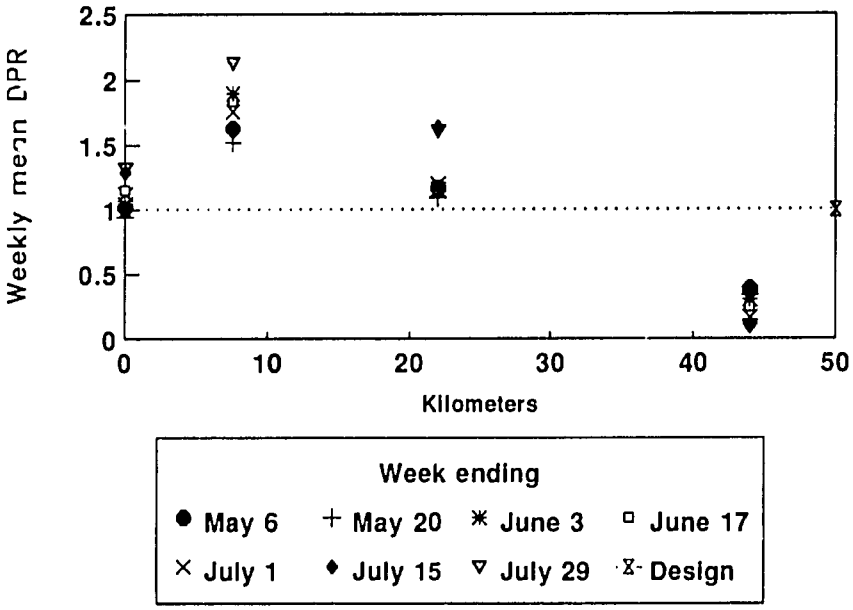
Variability in distributary flows upstream is passed on to the discharges of downstream off-taking watercourses. The effect is most pronounced for tail-reach outlets, and farmers in those command areas experience the further disadvantage of greater unreliability in the delivery of whatever share of surface water supplies reaches them. Mananwala Distributary operations (Figures 8.8-8.11) better illustrate this condition than does Pir Mahal because of the complex program of rotational deliveries practiced in the latter, even though careful head-gate operations at Mananwala do minimize the effect of variability in main system flows entering the distributary system. The conditions shown are for eleven *warabandi* weeks (Monday through Sunday) covering the first half of kharif 1990, May through July. It will be immediately observed

Figure 8.5. Dry days of Pir Mahal Distributary Outlet: Kharif 1988 and 1989.



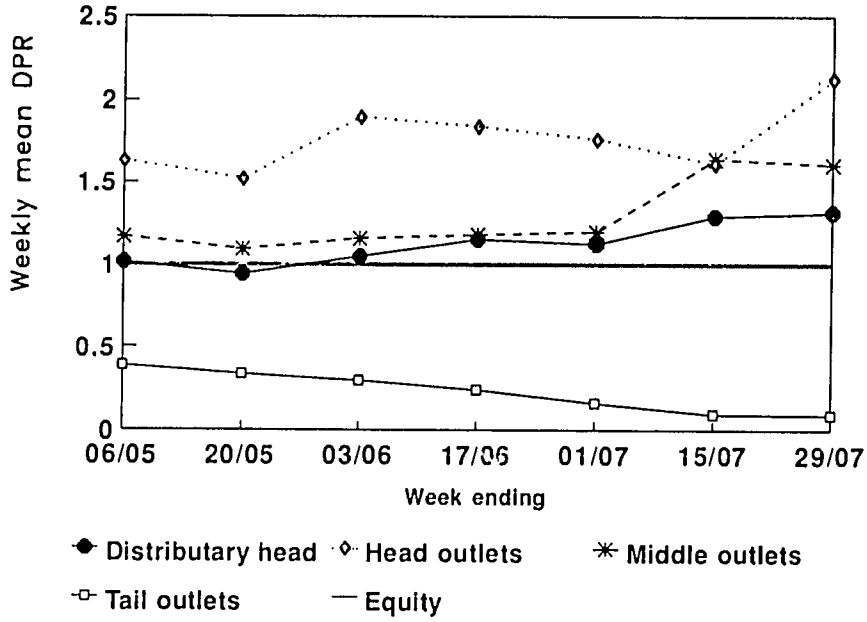
(n > 200)

Figure 8.6. Mananwala Distributary: Selected weekly mean DPR of sample outlets.



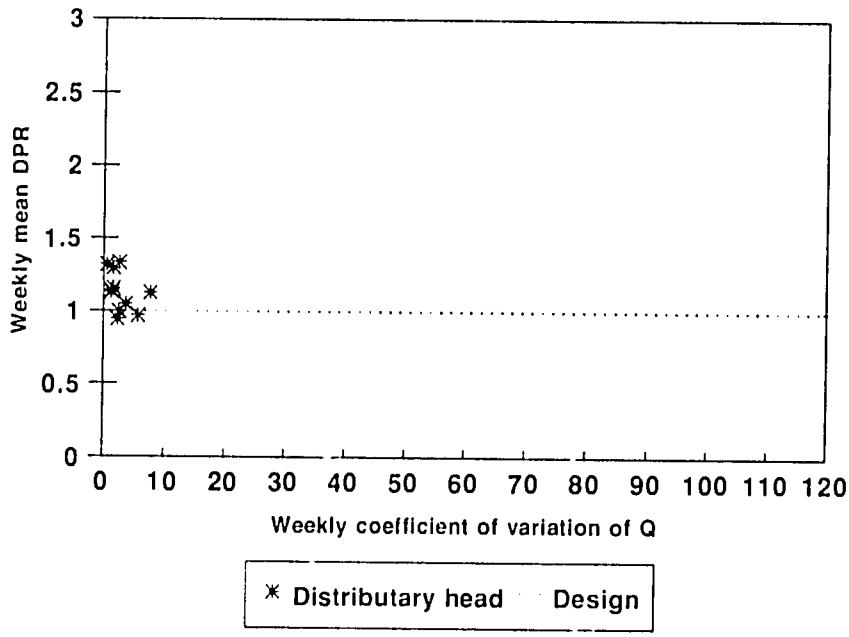
Clusters of sample watercourses
May thru July, 1990 only

Figure 8.7 Mananwala Distributary: Changes in mean DPR of sample outlets.



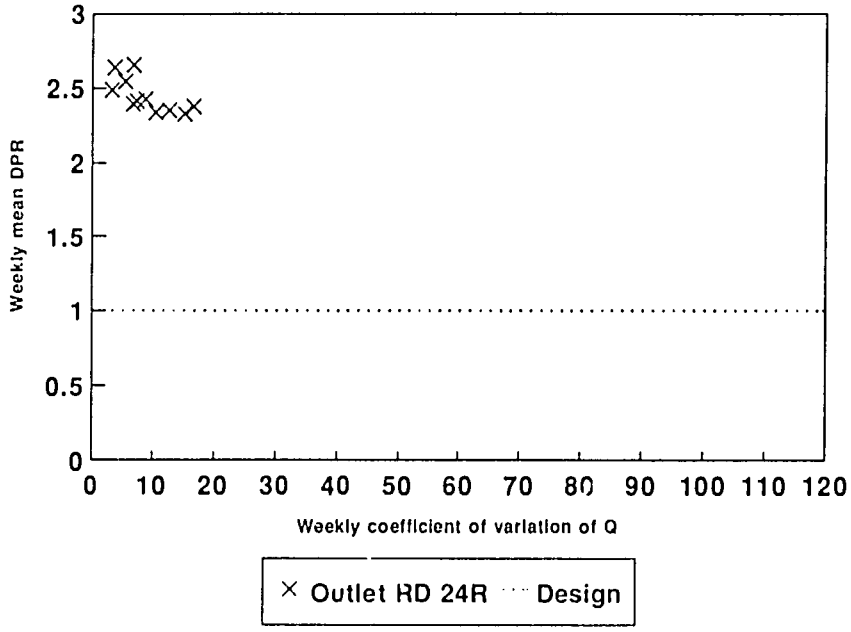
NB: May thru July, 1990

Figure 8.8. Mananwala Distributary Head: Equity versus variability, kharif 1990.



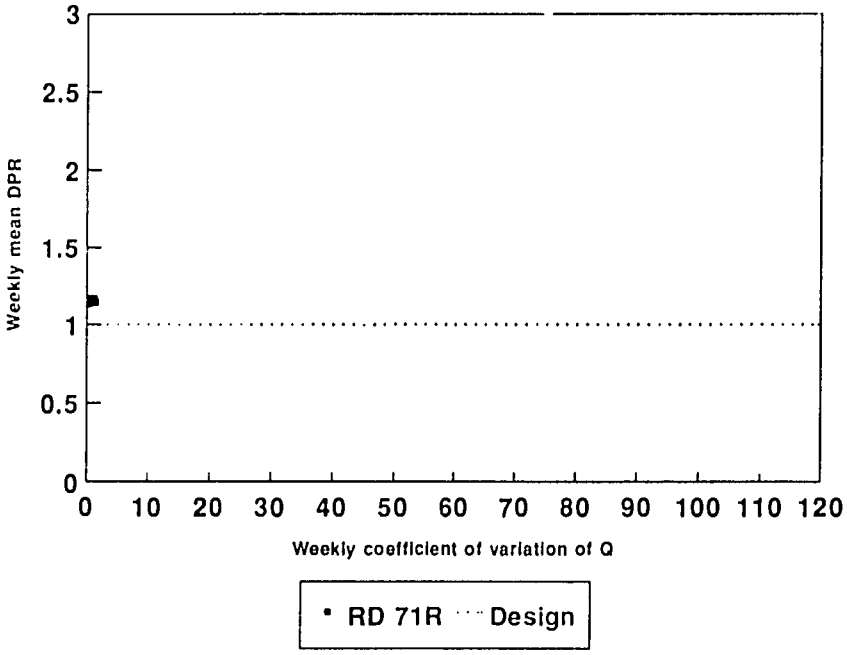
May-July, 1990 (11 weeks)

Figure 8.9. Mananwala Distributary Outlet RD 24R: Equity versus variability, kharif 1990.



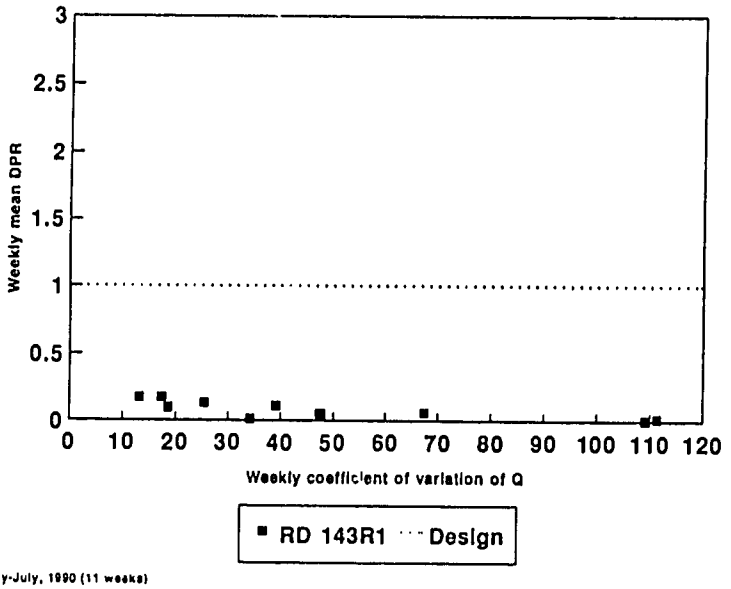
May-July, 1990 (11 weeks)

Figure 8.10. Mananwala Distributary Outlet RD 71R: Equity versus variability, kharif 1990.



May-July, 1990 (11 weeks)

Figure 8.11. Mananwala Distributary Outlet RD143R1: Equity versus variability, kharif 1990.



that for the distributary head, as well as for a head and middle watercourse, weekly mean DPR is near to, or well above, design. Variability associated with these flow conditions is correspondingly low, the coefficient of variation being well under 20 percent in the majority of instances. Variability of flows at a large tail watercourse, however, increases markedly as weekly mean DPR declines to virtually zero over the period.

DISTRIBUTION OF WATER SUPPLIES: GROUNDWATER IRRIGATIONS SYSTEMS

In the face of the increasing inability of the surface irrigation system to deliver water equitably in any usable amount to many watercourse heads in the lower reaches of distributary channels for extended periods of the year, the farmers' only apparent recourse is groundwater development. Indeed, it was the extensive program of public groundwater development in large areas of the Rechna Doab commanded by the LCC system — the SCARP deep drainage tubewells to control waterlogging installed in the early 1960s — that first provided greatly enhanced water supplies at the watercourse level and spurred two major, almost simultaneous, changes in irrigated agriculture there. These soon spread throughout much of Punjab. On the one hand, the three- or four-fold increase in water supplies at the watercourse level meant that the previous design low cropping intensities of the surface irrigation system — typically in the range of 50 percent-75 percent — could be exceeded, and annual cropping intensities in

canal commands rose rapidly to well over 100 percent. On the other hand, the greater abundance of irrigation water now available to farmers meant that large acreages could be planted with more remunerative, but more water intensive, crops such as rice and sugarcane.

The unforeseen and relatively rapid decline in the amount of fresh groundwater pumped by these deep tubewells — due to the shorter than anticipated bore life, frequent breakdowns in pumps and motors, poor maintenance levels, power supply constraints, high operating costs, and inadequate budgetary resources — does not mean that the contribution of public tubewells to the irrigation water supplies of farmers has now become insignificant. Farooqabad Sub-Division falls wholly within the SCARP I area, and Johnson (1990) has reported that the average annual utilization rate of 11 public tubewells located in the command areas of Mananwala Distributary and neighboring Lagar Distributary was 64 percent in 1988-1989, based on the number of hours that each well was operational with electric power available.

In the sample of nine Lagar Distributary watercourses where public tubewells remain operational, detailed monitoring and measurement of their operations throughout the 1988-89 agricultural year were carried out. The data revealed that public tubewells provided, on average, 43 percent of all irrigation water available to farmers in rabi and nearly 30 percent of irrigation supplies available in kharif.

Nevertheless, the amount of groundwater supplied by public tubewells that remain in operation has declined substantially from levels achieved in their early years of operation. They no longer provide a threefold or greater increase in water availability at the watercourse command — in the Lagar study, average irrigation supplies from the public tubewells exceeded those from the distributary by only 25 percent in either season. Indeed in many watercourse commands throughout SCARP I, the public tubewell is no longer operational at all.

It has been the rapid development of private, shallow tubewells throughout the 1980s that has offset the declining productivity of the public deep tubewells and in large measure made it possible for farmers to maintain high cropping intensity levels and cropping patterns, with substantial areas planted to more water-consumptive, less drought-tolerant crops. The growth in numbers of private tubewells has been most rapid in Punjab (Figure 8.12).

The censuses of tubewells done by IIMI in 35 watercourse commands of Mananwala, Karkan (Minor) and Lagar distributaries reveal that the average density of private tubewells in Farooqabad Sub-Division is about 5 per 100 ha of gross command area (GCA).[40] This density of private tubewells, in a SCARP area where private tubewell installation was formally restricted and controlled, is considerably higher than what published official data have indicated (Figure 8.13). The implication is that the pace and pattern of private tubewell development may well have been substantially underestimated for large areas of Punjab.

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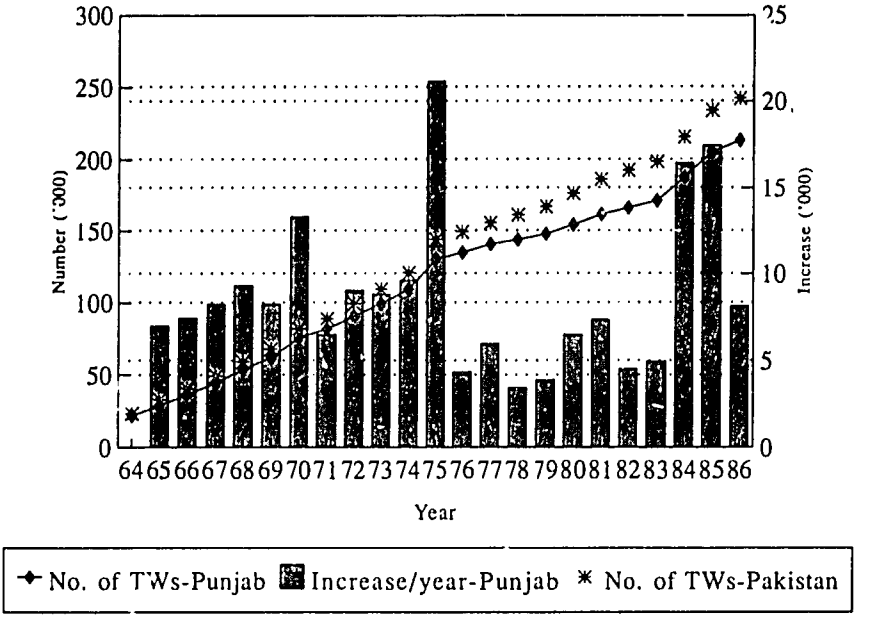
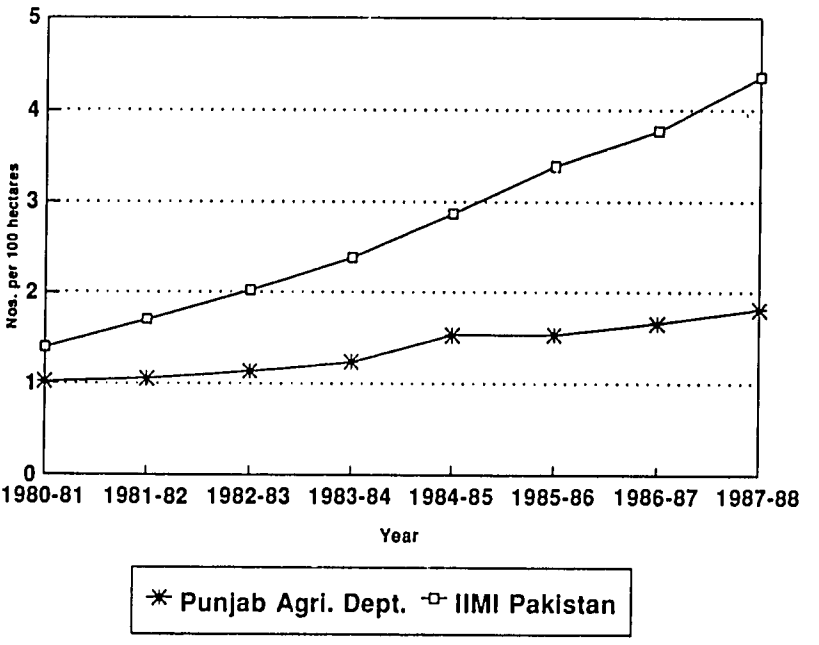
[40] Watercourse gross command area (GCA) is used here rather than cultivable command area (CCA) because CCA more strictly applies to the irrigable service area of the surface system. Many farmers have installed tubewells not only to supplement their surface supplies, but also to bring additional areas, not served by the surface system, under irrigated agriculture.

Figure 8.12. Private tubewell development in Pakistan and Punjab.



Source: WAPDA, 1988

Figure 8.13. Densities of private tubewells: Punjab Agriculture Department data versus IIMI data.

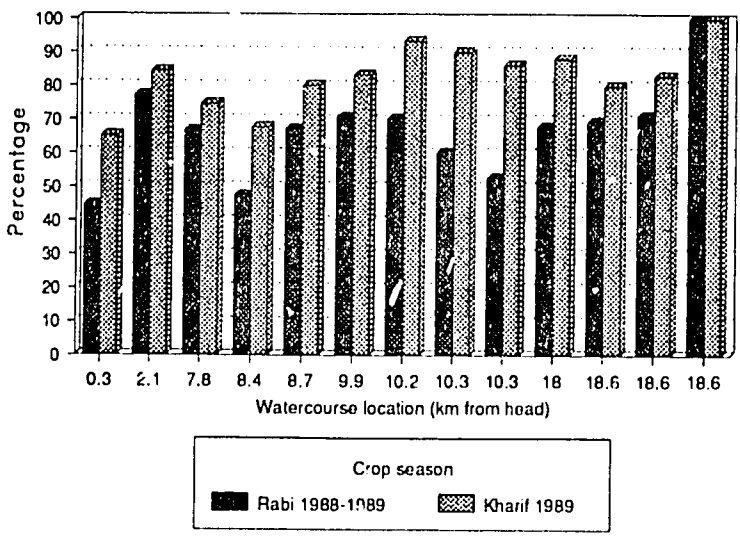


IIMI = Farooqabad SD canal watercourses
PAD = Sheikhupura District

In any event, the actual availability of water in watercourse command areas continues to exceed the original surface system design values of 1 l/s per 5 or 7.5 ha noted above. In fact, IIMI data for 13 watercourse commands of Lagar Distributary indicate that the average proportion of groundwater to all irrigation water available to farmers at the pump head and the outlet was 67 percent for the rabi season, rising to over 80 percent in kharif. Figure 8.14 shows the spatial distribution of this pattern for different watercourse commands at increasing distances from the distributary head.

The ratio of groundwater to surface water annually available to farmers in Lagar command ranged between 1.2:1 and 14.7:1 for the 13 watercourses studied. If the extreme value of 14.7:1, which occurred in a tail-end watercourse, is ignored, the average annual ratio of groundwater to surface water is 2.8:1. It is therefore reasonable to assume that on average groundwater from public and private sources contributes about 70 percent of the total irrigation water used in irrigated agriculture in Farooqabad Sub-Division.[41] Significantly, data collected in the command area of watercourse RD 89, Pir Mahal Distributary, in kharif 1990, indicated that during July and August, groundwater contributed 72 percent of the total irrigation water used by farmers in the area.

Figure 8.14. Percent of groundwater in total irrigation water used: Lagar Distrbutary command.



[41] At IIMI's 1989 Internal Program Review, Johnson and Vander Velde reported on the de facto conjunctive management of surface water and groundwater in these distributary and watercourse command areas.

These findings provoke the tentative conclusion that groundwater resources are providing a substantially greater proportion of total irrigation supplies now utilized by farmers in many canal command areas in Punjab than previously suspected. They may also imply a rate of aquifer exploitation already in excess of recharge, at least locally if not over larger areas. Perhaps most important is the fact that no agency or organization in Pakistan is systematically monitoring what appears to be a fundamental (and possibly short-lived) transformation of the water resource basis of the Indus Basin irrigated agriculture system.

THE WATER BALANCE

There are several reasons for seeking to ascertain the water balances of watercourse command areas. First, we want to know how much water is consumed by crops and how much is lost to groundwater, contributing to aquifer recharge and perhaps water table rise. The Second concern is to determine what proportions of the irrigation water that farmers use are derived from canal supplies and from groundwater. Once the proportionality of supplies and their quality have been determined, the key issue of whether the salt content in the crop root zone is likely to increase or decrease can be tackled.

In several sample watercourse command areas in the LCC system, water flows into the watercourse from the secondary canal system and discharges from public and private tubewells have therefore been recorded by IIMI field teams over sustained periods in 1989 and 1990. Additionally, irrigation applications have been measured in fields of sample farmers in these watercourse commands, to evaluate farmers' irrigation practices. Seasonal irrigation applied to wheat during rabi 1989-90 is presented in Table 8.1. All irrigations in Mananwala were from public tubewells, and all but two irrigations in Pir Mahal were from private tubewells.

Although the average seasonal irrigation is about the same in both areas, the variability of seasonal irrigation is greater in Mananwala command than in Pir Mahal command, as can be seen from the standard errors. The average amounts applied per irrigation differ significantly (5 percent level) between the two areas. It is not clear why some farmers apply much more water than others, or why a farmer applies twice as much water from the same tubewell to one field as to another. This is especially true for Mananwala area, where the variability in irrigation applications is greater than in the Pir Mahal area. Apparently, farmers in the Pir Manal area attempt to make more optimal use of their irrigation water.

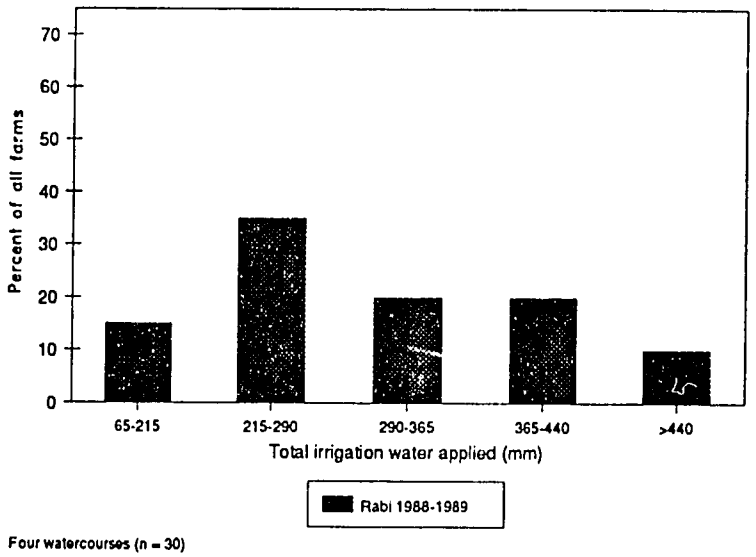
Histograms depicting irrigation applications to wheat during rabi 1988-89 and to sugarcane during kharif 1989 are shown in Figures 8.15 and 8.16. The data reflect farmers' practices in watercourses of Mananwala and Pir Mahal distributaries, in addition to the sample watercourses mentioned above. The median irrigation application for wheat in the Mananwala area is 290 mm. Median values for irrigation of sugarcane are 480 mm in Mananwala and nearly the same, 485 mm, in Pir Mahal. The histograms again illustrate the wide range of irrigation applications practiced by

farmers; some obviously overirrigate while others apply hardly enough to make it worth their while harvesting the crop.[42]

Table 8.1. Wheat irrigation in two LCC distributary canal commands: Rabi 1989-1990.

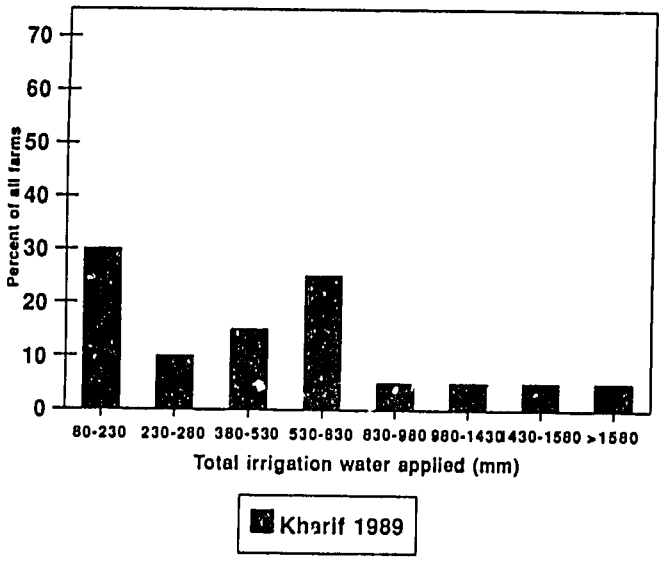
	Mean total irrigation (cm)	Std. error	Mean application (cm)	Std. error	Average no. of irrigations	Total rainfall (cm)
Mananwala	22.0	2.1	7.0	0.42	2.5	14.7
Pir Mal.	21.2	0.7	6.2	0.16	3.8	9.6

Figure 8.15. Irrigation of wheat: Mananwala Distributary command.



[42] The data used in Figures 8.15 and 8.16 were obtained from a much larger sample of farmers in four districts of Punjab which will be reported on in greater detail elsewhere. Mean and median values of irrigation applications determined for the larger sample are significantly higher than the values mentioned here for Mananwala and Pir Mahal. The inclusion of data from Gujranwala District, which is not short of water, in the larger sample probably explains the difference. The results from the larger survey also strengthen the conclusion that irrigation practices of Punjab farmers vary widely.

Figure 8.16. Irrigation of sugarcane: Mananwala Distributary command.



Four watercourses (n = 30)

Substantial variability in both watercourse and tubewell discharge has been observed.[43] Variability in watercourse discharge is largely a function of distributary performance, as previously discussed. Variability in tubewell discharge, observed for all types of tubewells, results from a variety of factors. For electric tubewells, it is often a consequence of voltage fluctuations or an increase in drawdown of the water table following many hours of sustained pumping operations. In diesel- and tractor-powered tubewells, significant fluctuations in discharge can also result from changes in engine speed with throttle adjustments. Long-term decreases in tubewell discharge can be expected with motor wear and tear, as well as from the deterioration of screens.

The operating hours of tubewells have been determined through farmer interviews, from the calibration of the electric meters against individual wells and motors, and from the recordings of vibration meters. Although there are bound to be errors associated with all observations and measurements relating to both tubewell discharges and operating hours, IIMI data now provide the most reliable and extensive information on tubewell irrigation operations within surface system canal commands available in Pakistan.

Some components of the water balance for a watercourse command area have not been measured, but have been deduced from previous studies done elsewhere. An example is the case of conveyance losses in watercourses, which have been reported

[43] Temporal variability in the discharges of watercourses and various tubewell types have also been monitored with automatic stage recorders.

by Trout et al. (1980) and WAPDA (1984). Thus, a conveyance efficiency of 55 percent — the average reported for SCARP areas — was used in the water balance study of Mananwala watercourse RD71.[44]

Losses from nonrice crops depend on the assumed value of field application efficiency. WAPDA (1978) has estimated these efficiencies for a range of irrigation conditions, and its determination of an average application efficiency of 58 percent for tubewell-supplemented watercourse commands could be used for Mananwala watercourse RD71. However, modeling studies (discussed below) indicate that percolation losses from the irrigation of nonrice crops depend on soil characteristics and are probably lower than those previously reported by WAPDA. Hence, an application efficiency of about 70 percent may be attainable where water is in short supply. Losses from rice fields were measured during kharif 1989 and 1990 from the rate of decrease of water levels in ponded rice fields, corrected for evaporation losses. The measured rate in RD71 was 5.8 mm/day for the 80 percent of the time that the fields were observed to be ponded or moist.

Table 8.2 shows the estimated quantities of water reaching the water table and being abstracted from it over a period of 78 days during kharif 1989. Each quantity is a total volume for the period, converted to an equivalent depth over the CCA of the watercourse. Conveyance losses and losses from rice fields contribute most to the groundwater recharge. Between the two values of the application efficiency used, 58 percent and 70 percent, there is only a relatively small change in the residual.

Table 8.2. Water balance at the water table in Mananwala RD71: Kharif 1989.

Application Efficiency	58%	70%
Conveyance losses	179 mm	179 mm
Application losses	43 mm	31 mm
Percolation losses from rice fields	166 mm	166 mm
Distributary losses	15 mm	15 mm
Change in aquifer storage	6 mm	6 mm
Pumped abstractions	– 398 mm	– 398 mm
Residual	11 mm	0 mm

Obviously, the continuing uncertainty of some values of the water balance in Table 8.2 permits only a few general observations. Over the study period, recharge and

[44] Although this watercourse is lined, it is in poor condition and there is no reason to assume a higher efficiency because, as Wachyan and Rushton (1987) have reported, while perfect lining will prevent all seepage losses, linings that have cracks and other imperfections result in only small reductions in conveyance losses.

discharge from the aquifer appear to balance. This is supported by observations of water table depth in 20 observation wells distributed throughout the command area of RD71, which revealed an increase of around 1 m coinciding with the onset of percolation from rice fields, followed by a return to the original level at the end of the field study. The fall in the water table during the second half of the study period is ascribed to the noted increase in tubewell abstractions. The fact that percolation from rice fields is of the same order of magnitude as the daily evaporation-cum-transpiration rates indicates that the soils in the area are too light for efficient rice cultivation. In fact, rice fields were often observed to be dry. As submergence of rice fields also is intended to suppress weed growth, it is not surprising to find considerable weed growth in these rice fields. Farmers do not seem to mind this, however, as weeds are cut for fodder.

The contribution of rainfall to water table rise remains undetermined in this research. However, it is considered to be small, because no sharp rise in water table was observed after a 100-mm storm early in the study period, or from later smaller storms. If 20 percent, a value reported by Michael (1978), of the 100-mm storm had percolated to the water table, a rise in water levels of around 133 mm could have been expected in the following 3 to 4 days. This was not observed, and it is concluded that most of the rainfall entered the soil profile as storage, either in or below the root zone.

WATER QUALITY

The suitability of irrigation water for agriculture should be evaluated on the basis of the specific conditions of use, including the crops grown, soil properties, irrigation management, cultural practices, and climatic factors. The ultimate method for assessing the suitability of water for irrigation should consist of predicting the composition and matric potential of the soil water resulting from the use of the water, and interpreting such information in terms of how soil conditions are affected and how the crop would respond under any set of climatic variables (Rhoades 1972). Published tolerances of agricultural crops for salinity apply from the late seedling stage to crop maturity. There are not sufficient data to compare salt tolerance at different growth stages, but it appears that tolerance during germination and early seedling stage for some of the more tolerant crops may be lower. This may explain the frequently observed poor stands of wheat, for instance, which is a medium tolerant crop.

The SCARP Monitoring Organization (SMO) of WAPDA uses three long-recognized criteria for classifying irrigation waters, i.e., the electrical conductivity (EC), the residual sodium carbonate content (RSC), and the sodium absorption ratio (SAR). The usable or "fit" class extends to EC of 1.5 deciSiemens per meter (dS/m, equal to mmhos/cm),

RSC to 2.5 meq/l and SAR to 10.[45] The limits of these classes have continued to be applied to determine the suitability of water quality for irrigated agriculture as though no progress has been made in the understanding and interpretation of water quality subsequent to the publication of Handbook 60, in 1953, by the United States Salinity Laboratory, Riverside, California. Current guidelines for the interpretation of water qualities (e.g., Ayers and Westcot 1985) put the upper limit for no restriction in use at an EC value of 0.7 dS/m, i.e., less than half the value currently followed by the SMO.

The effect of sodium, as expressed in the SAR value, depends on the EC value, but a general upper limit for no restriction on irrigation usage of the water now would be set at 6 or 7, again much less than the SAR value of 10 still used by SMO (Lennaerts et al. 1988). For sodic waters, as in much of Punjab, an adjusted SAR is recommended as a generally better index (Rhoades 1982), wherein the calcium concentration is taken as the concentration that will result in the soil solution upon equilibration of the soil and irrigation water. Sodium adsorption ratios of typical tubewell waters increase by around 25 percent when they are calculated as adjusted SAR values. This reinforces the notion that it is not advisable to classify tubewell water with SAR up to 10 as suitable for irrigation use undiluted.

The official view of WAPDA is that "the usable waters are not expected to create any salinity or sodicity problems in the soil and can be safely used to raise all type of crops climatically adapted in the area even without mixing with canal water provided efficient drainage is practiced" (WAPDA no date). It needs no further explanation that in water-short environments, such as has been observed at the tail ends of distributary channels and watercourses, drainage is neither practiced nor needed as no excess water can be given. Moreover, as has been seen, there are scant opportunities in these locations to implement the recommended practice of mixing or using canal and "marginal" quality groundwater at a one-to-one ratio.

The first detailed consideration of tubewell water quality was undertaken by IIMI in the command area of the Lagar Distributary in 1988 and 1989 (Vander Velde and Johnson 1989; Johnson 1990). The water quality of a large number of tubewells in Lagar command was determined as part of a study of tubewell performance carried out in collaboration with the Punjab Irrigation Department's Irrigation Research Institute. A similar, though larger, study of tubewell and surface-system operations was initiated in kharif, 1990 in a sample of watercourse commands in the Mananwala Distributary system. The Irrigation Research Institute again has done tubewell discharge calibration and water quality sampling.

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[45] WAPDA's EC and SAR values for "marginal" irrigation water (i.e., that which is recommended to be used mixed 1:1 with canal water) are 1.5 < 2.7 dS/m and 10 < 18, respectively. When EC > 2.7 dS/m and SAR > 18, water is too harzardous to be used for irrigation without extensive mixing with good quality water at unspecified ratios. In fact, two different classifications of the suitability of water for irrigated agriculture are widely used in Pakistan. That established by WAPDA, and referred to in this paper, is the least conservative and possibly the most widely followed in the country. A more conservative classification is followed by the Directorate of Land Reclamation of the Department of Irrigation, Punjab. Usable or fresh water has an EC < 1.0 dS/m in this case, although the upper limit of SAR remains unchanged at 10.

Data for 137 tubewells, 69 percent of the total in the command area of Mananwala Distributary, are shown in Figures 8.17 and 8.18. Histograms reveal the spatial distribution of two water quality criteria, EC and SAR, of 31 tubewells in the head reach, 46 tubewells in the middle, and 60 tubewells in the tail reach of Mananwala Distributary.[46] The differences between the mean values of EC and SAR for head, middle, and tail watercourse commands are significant (1 percent level), indicating deterioration of tubewell water quality towards the tail of the distributary.

The pattern is the same for another 50 tubewells (out of a total of 104) in the command of Karkan Minor, offtaking from the Mananwala Distributary at RD 76 (i.e. 23 km from the head of Mananwala Distributary). The values of both EC and SAR are higher along Karkan Minor, than for a comparable distance along Mananwala. If the tubewell data for Karkan Minor are also grouped according to head, middle and tail, the mean values are 1.4 dS/m and 9.2 for EC and SAR, respectively in the head reach, 2.0 and 12.4 in the middle reach, and in the tail reach 3.0 and 18.2. A similar spatial pattern of marked decline in the quality of water pumped by both public and private tubewells from head to tail watercourses in Lagar Distributary command also was found in research carried out there in 1989 which covered about 175 tubewells.

Further analysis of 85 tubewells in the Mananwala command area revealed that even according to the SMO's less conservative criteria, merely 30 tubewells are producing water that is considered fit for irrigation. If the more restrictive and recent FAO criteria (Ayers and Westcot 1985) are applied, none of the tubewell water would be found suitable for direct use in irrigated agriculture, without first being mixed with water of a better quality.

Two possible explanations can be considered for the apparent decline in water quality towards the tail of the distributary. First, more irrigation water is applied per unit cropped area in the head reach because of the combination of the greater availability of canal supplies augmented by tubewell water, the generally better quality of irrigation water that is available, and the larger area planted to more water consumptive crops.[47] Alternatively, the primary source of recharge in the area (the Upper Gugera Branch and the Q-B Link canals, as previously noted), is closer to the head of the distributary than to its tail reach. Evidence for accepting or rejecting either hypothesis is insufficient at present and it is bound to require substantial research on aquifer behavior. Moreover, it may be that the observed decrease in groundwater quality towards the distributary tail can be ascribed to a combination of the two and perhaps other phenomena.[48]

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[46] Residual sodium carbonate (RSC) has not been included in this discussion because an analysis of previous RSC data revealed that the laboratory determinations of RSC were highly unreliable. Moreover, the soundness of using RSC for evaluating suitability of irrigation water has begun to be questioned as a result of the underlying assumptions related to quantitative precipitation.

[47] Canal water quality is markedly better than the best quality tubewell water, with ECs at about 0.2 dS/m for canal water versus 0.6 dS/m for the best tubewell water.

[48] Our colleague, Dr. R. Sakthivadivel, has suggested that the vertical differential hydraulic gradient existing between the distributary head and tail also could contribute significantly to accelerated salinity differences between these locations.

Figure 8.17. Frequency distribution of EC: Mananwala Distributary command.

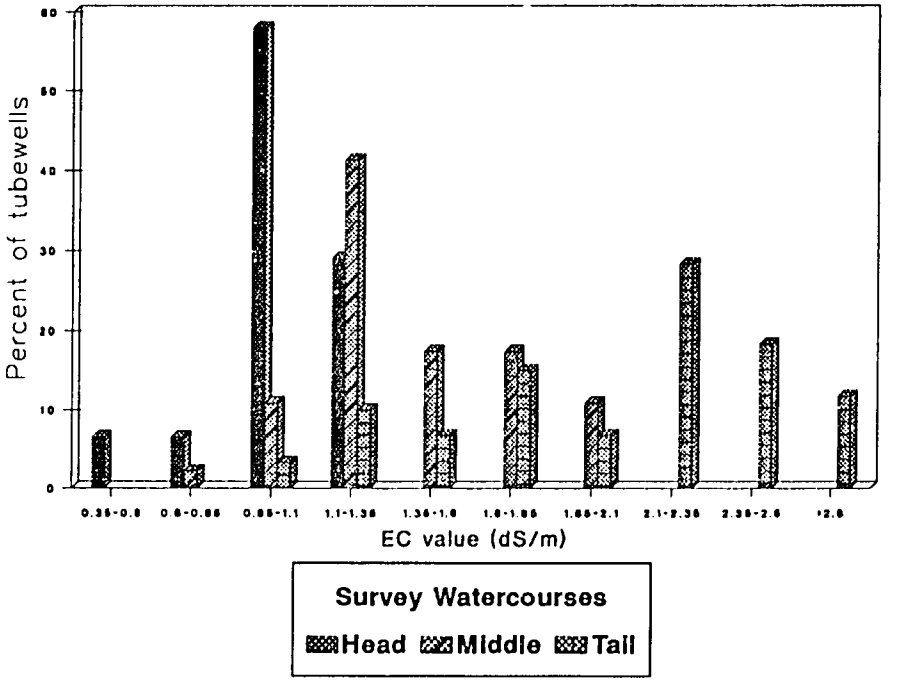
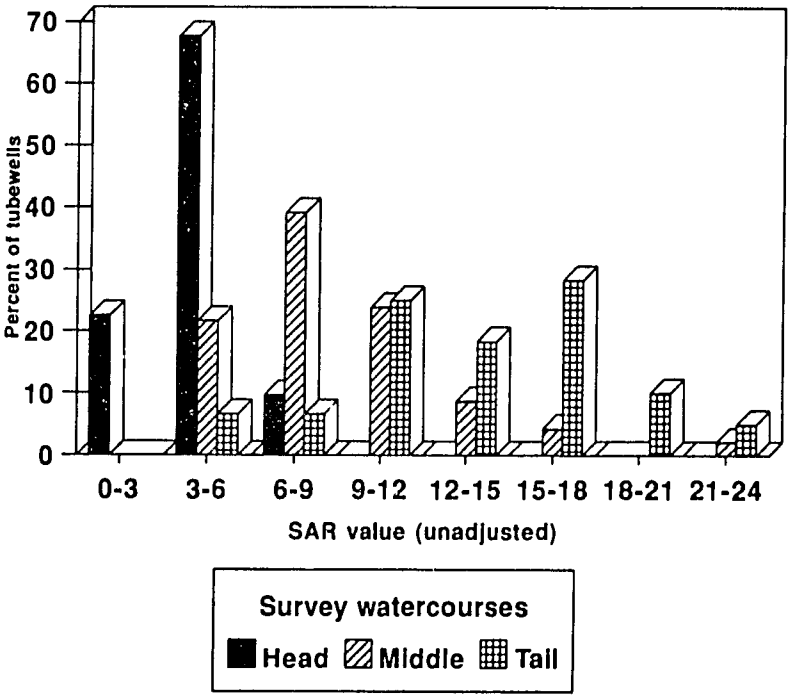


Figure 8.18. Frequency distribution of SAR: Mananwala Distributary command.



It is important to note that the installation of the majority of tubewells in the command area is comparatively recent. Forty-three percent of the tubewells in the head reach watercourses were installed after 1987, as were 40 percent in the middle reach, but merely 11 percent at the tail. By contrast, 40 percent of the tubewells in the tail reach watercourses were installed before 1985, but only 20 percent in the middle and 6 percent in the head reach are more than five years old. Clearly farmers in tail watercourse commands felt the need to install tubewells at an earlier date than did those in the middle and head reaches of the distributary. This is not surprising, of course, considering that tail-end farmers must have begun experiencing persistent shortages and greater variability in canal-water supplies at a much earlier date.

Evidence that proximity to sources of groundwater recharge is the primary cause for better quality tubewell water to be found in head reach watercourses is circumstantial at best. Although the head watercourses of Mananwala Distributary are within an area that is certainly recharged by losses from the parallel Upper Gugera Branch and Q-B Link Canals, the distributary's alignment is such that its middle reach is actually farthest away from apparent sources of recharge. Mananwala tail is slightly closer to Upper Gugera Branch, which it roughly parallels at a distance of about 10 km. However, it is unlikely that Upper Gugera Branch alone (now the only apparent source of aquifer recharge insofar as the much larger Q-B Link Canal is no longer flowing parallel to it, having continued on its course in a southerly direction) can provide anything like the amount of recharge that the two canals together do for the Mananwala head area. Nor can the observed similar decline in groundwater quality between head and tail watercourses within Lagar Distributary command be readily ascribed to increasing distance from recharge areas, since there is no significant locational change throughout its alignment, relative to the same apparent source of recharge. What is needed here, of course, as elsewhere throughout the commands of Punjab's many canal systems, is a much more accurate and detailed understanding of aquifer recharge and behavior than is presently available.

If deterioration of groundwater is indeed substantially a consequence of the seepage of saline water from lands irrigated with marginal or poor quality tubewell water, it is important to note that the process is apparently relatively fast. Public tubewells pump, on average, from a depth of 50-100 m, and private ones from 15-30 m.[49] With a water table at about 5 m depth, it has taken only 5 years (the median age of tubewells in Mananwala's tail reach) to worsen groundwater quality down to at least 15 m. Records of public tubewells should show a decline in water quality if the effect has reached even greater depths. However, data collected by WAPDA's SMO point to a tightening of the water quality values (poor quality tubewells improving and good quality tubewells deteriorating), without a significant change in average water quality over time (Johnson 1990).

Interestingly, Kung (1990) has recently described preferential flow paths in sandy vadose zones (the layer between the water table and the root zone) as the mechanism through which groundwater contamination can take place over a short period of time.

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[49] In public tubewells, the screen begins at a depth of around 45 m and extends to about 100 m; private tubewells are screened from a depth of about 15 m to 30 m.

He is of the opinion that "funneled flow" occurs widely in most vadose zones. Because preferential flow paths recharge the water table at distinct points, the dispersive nature of these point sources of contamination at the water table should lead to a wide scatter of quality values over short distances, which is precisely what has been found in all IIMI study areas when sampling groundwater quality in observation wells and from tubewell discharges.

SALINITY IN SOIL PROFILES

To assess the likelihood of a salinity problem for conventionally irrigated and established crops, the mean salinity of the major root zone, i.e., where most of the water extraction occurs, should be determined. To avoid a salt problem anywhere in the cropped area, the maximum salinity observed should be taken as the salt index for the field. But if salt problems are permitted to occur in about 15 percent of the area, the sum of the mean and the standard deviation could be used as the salt index (Rhoades and Loveday 1990). The value of the salt index thus obtained can then be compared with that of the salt tolerance of the crops to be grown. Salt tolerances of established crops based on growth and yield have been reported (e.g., ibid.) in terms of their threshold values and percentage decrease in yield per unit increase of soil salinity in excess of the threshold.

Soil salinity is conventionally expressed in terms of the electrical conductivity of the extract of a saturated soil paste (ECe in dS/m). It has been suggested (ibid.) that improvements in diagnosis can be made by using the salinity of the soil solution per se, rather than that of the saturation extract, since the latter does not account for the increase in salinity that the soil water undergoes between irrigations due to soil water depletion.

Electrical conductivity measurements were made in situ in fields of sample farmers during rabi 1989-90 and kharif 1990 with a resistance bridge and salinity sensors that are meant to be left in place in the root zone to monitor salinity changes during the season.[50] Results from 182 fields sampled in this way are shown as histograms of mean profile salinity in Figure 8.19. As was expected, profile salinity ranges widely, and was higher in the tail watercourse commands, Mananwala RD143 and Pir Mahal RD133, than elsewhere.

For the interpretation of these values, it should be realized that an EC value of 5 dS/m corresponds to an osmotic potential of -2 bars, 10 dS/m to -4 bars, etc. The effects of osmotic potential and matric potential (decreasing as the soil dries from water absorption by plant roots) are additive. In general, photosynthesis and transpiration are reduced when the total potential — the sum of matric and osmotic components — drops below -4 to -5 bars.

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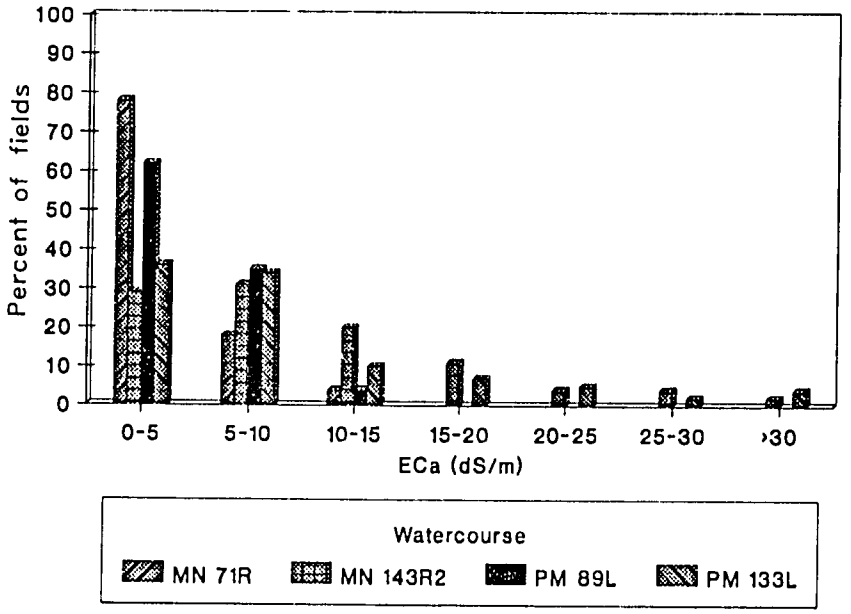
[50] Because of physical interference with the equipment, the sensors could not be left in the field. Soil samples were therefore taken from farmers' fields to the IIMI's field station, where the sensors were then buried in the samples and the EC determined after equilibrium had been reached.

Figure 8.19. Soil salinity of four watercourse commands of Mananwala and Pir Mahal distributaries.



In one-third to one-half of all fields sampled in the tail watercourse commands, profile salinity was found to be sufficiently high to reduce crop photosynthesis even when the soil is at field capacity. Even in the middle reach watercourse commands, profile salinity in 5 percent of the sampled fields had reached such a level; significantly, those levels were concentrated in the tail areasof those watercourses. In short, under such conditions crops are stressed despite the fact that there is plenty of moisture in the soil. It is not surprising, therefore, that crop yields in these locations are below expected, let alone potential, levels.

The conversion of the apparent electrical conductivity values (ECa) to the more familiar ECe values for calculating expected yield decreases, is not straightforward since the conversion factor to be used depends upon both the clay content and the soil water content at the time the ECa values were determined. For the average conditions represented by the soil samples, an ECa of 10 dS/m could be expected to cause a decrease of up to 40 percent in yield of a medium tolerant crop such as wheat, and a decrease of as much as 60 percent in the yield of sugarcane, which is medium sensitive to salinity. These are only indicative values, since the absolute salinity tolerances of crops also vary depending upon climate, soil conditions and cultural practices. Moreover, other factors which could be limiting crop production have not been considered in these estimates.

SODICITY

Sodicity may induce Ca deficiency and various other micronutrient deficiencies because the associated high pH and bicarbonate levels repress their solubilities and concentrations. All of the tubewell water surveyed and results shown in Figures 8.17 and 8.18 have high pH values — merely 15 out of 85 have a pH below 8 — as well as high bicarbonate values.

In contrast to normal and saline soils, sodic soils typically have reduced permeabilities and poorer tilth, resulting from a loss of structure and clay migration with the movement of sodic soil water. Soil permeability and tilth responses to irrigation should be assessed in terms of the salinity of the infiltrating water and the SAR value predicted to result after irrigation, using the adjusted SAR of the irrigation water. Some other soil parameters (e.g., clay mineralogy and content, organic matter content) are known to affect the acceptable levels of EC and adjusted SAR.

In the absence of information on the aggregate stability of the sample soils, a general guideline relationship based on EC of the irrigation water and SAR of the topsoil, has been used to assess sodicity hazards of irrigation water (Rhoades 1982). The combinations of mean EC values and mean SAR values for all tubewells surveyed in head, middle, and tail watercourse commands of Mananwala Distributary, as shown in Figures 8.17 and 8.18, barely fall inside the range of unlikely permeability hazard. About one-quarter of the tubewells in the tail-reach watercourses, however, have EC and SAR values that are within the range of waters likely to cause permeability problems.

In April 1990, field staff carried out a rapid appraisal survey to record the visual presence of salinity — either as surface salting or obviously salt-affected crops — in the command areas of 7 watercourses of the Mananwala Distributary, including RD71 and RD143, covering a total of 1,206 ha. At the same time, the presence of dense, hard layers was also assessed by probing the soil with a narrow probe to feel the resistance in the top 50 cm of the profile. An increased resistance could be a possible indication of clay migration and reduced soil permeability. In 4 percent of the total area surveyed, the effects of salinity were observed and in 76 percent dense layers were present. However, when just the tail-reach areas of watercourses and distributaries are considered, these proportions are 17 percent for presence of salinity and 79 percent for dense layers. By contrast, for head-reach areas only, there was less than a 1-percent incidence of salinity and a 51-percent occurrence of dense layers. These data strongly reinforce the conclusion of a general deterioration in soil conditions towards the tail within distributary canal commands due to secondary salinity.

In addition, saturated conductivity was determined by IIMI field teams with a Guelph permeameter in over fifty fields in sample watercourse commands of both Pir Mahal and Mananwala distributaries. Infiltration rates were determined with single ring infiltrometers in an equal number of sample fields. Large spatial variability of saturated permeability and basic infiltration rates were observed, and zero values for both parameters were often recorded in salt affected fields. The median values of the (non-zero) saturated permeability rates were used to characterize the soil for modeling purposes, which is discussed in greater detail below.

With respect to the problem of sodicity, the field observations we have just described point towards a structural decline of soils resulting from irrigation with sodic irrigation waters. This has important implications for the reclamation of soils by leaching.

SALT BALANCE

The removal of salts from the root zone, to maintain the soil solution at a salinity level compatible with the cropping system, requires a downward flux of water and salts in the soil below the root zone. The fraction of infiltrated water that passes through the root zone is called the leaching fraction. A salt balance has been attained if, through this leaching process, the total salt content in the root zone remains constant. Hence, sufficient irrigation water, combined with rainfall, must be applied over and above the evapotranspiration needs of the crop, so that there is excess water to pass through and beyond the root zone and to carry away salts with it. This excess water is referred to as the leaching requirement.[51]

In order to predict the long-term consequences of irrigation with undiluted tubewell water of questionable quality, it is important to know the effect of sustained irrigation on soil salinity.[52] Through computer modeling and simulation of water and salt balances, it is possible to assess the effect of current farming practices on the build-up or removal of salts from the profile.

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[51] Recently, the concept of leaching requirement has been criticized (e.g., Smith and Hancock 1986). It has been argued that with the practical problems of water management at field level it is likely that the leaching fraction (i.e., the amount actually applied in excess of consumptive use requirement of the crop) will be more than the calculated leaching requirement, unnecessarily increasing the salt load of the drainage water. Leaching *fractions,* plausible under normal farming practices, have been calculated through the simulation of salt and water balances.

[52] Soil salinity was monitored in the field under sustained saline irrigation in northern India by Bajwa et al. (1986). The study was carried out on a well-drained loamy sand of lighter structure than most of the soils in our sample areas. Moreover, the irrigation water which was synthesized, had a combination of EC and SAR which puts it further into the range of unlikely permeability hazard than most of the tubewell water we have observed. This combination of differences suggests that the results of Bajwa's study are of limited applicability to the research reported here. Nevertheless, it is of interest to note that salinity increased rapidly in the soil profile during the initial years. After five years, the average soluble salt content in 0-90 cm profile did not vary appreciably and the mean ECe under sustained saline irrigation remained similar to the EC of the irrigation water.

Two computer models for water balance and salt balance have been used for this purpose.[53] The input data requirements of the model refer to basic properties of soils and plants. These include dependence of matric potential and unsaturated conductivity on water content; root depth during the season and fractional amount of active roots in a particular increment of depth; initial conditions of water content and soil solution concentration versus depth; boundary conditions of potential evapotranspiration rate, rainfall and irrigation amounts; and the presence or absence of a water table. The model has been tested under various environmental conditions (e.g., Nimah and Hanks, 1973) and used to generate results over several years which would otherwise be too costly to obtain through field studies (Hanks 1984). In general, good agreement is obtained between computed and measured water contents and salinity profiles. But the effect of salinity on crop yield is less frequently accurately predicted by the model.

We have used Hanks' model to simulate water and salt movement into and out of the root zone for three major crops grown in the command of the LCC system: cotton during kharif, wheat during rabi, and sugarcane over both seasons. Evapotranspiration rates were calculated from meteorological data and the other boundary conditions, including the initial water content and salt concentration derived from measurements in the field. Sand and clay contents were determined from representative soil samples collected when water table observation wells were installed in the sample watercourses of each distributary canal command. This information, combined with the measured saturated conductivities, was used to identify characteristic soil types based on soil data compiled by Wosten (1987, also Wosten and Van Genuchten 1988). The soil physical parameters, required as input for the model for the three soils chosen for modeling — a sandy loam, a silt loam, and a clay loam — were those characteristic for each type.[54]

Simulations were done for both the median EC value and the 75 percent value (i.e., values exceeded by 25 percent of the samples) of irrigation water qualities being pumped by tubewells and used by farmers in tail-end watercourse commands (see

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[53] R.J. Hanks, Utah State University ,was kind enough to make these models available for use by IIMI Pakistan. They are described in greater detail by Childs and Hanks (1975) and Hanks (1984). As with all models that are simplifications of complicated processes in reality, many critical assumptions must be made. In this case, the key assumptions involve the soil properties and the root extraction term. Although various attempts have been made to make these models more "realistic" by including additional plant factors, this has not resulted in better predictability when they are applied to actual field situations. The problem is further confounded, because as more parameters are included in the model, its use becomes restricted to research institutes with facilities for measuring the required data. The model, as used, already requires information that is not readily available in Pakistan (see Kijne 1989).

[54] An initial test of the validity of this approach was made during Rabi 1989-90 on six wheat fields in the command area of RD 133, Pir Mahal Distributary. The wheat fields were on two different soil types, and the model predicted the salinity and water content profiles at the end of the season satisfactorily. Detailed results of this work will be reported separately elsewhere.

Figures 8.17 and 8.18). Median irrigation applications for wheat grown in Mananwala Distributary command, and for cotton and sugarcane grown in Pir Mahal Distributary command, were used as input in the model. The results of these simulations are presented in Table 8.3.

Table 8.3. Simulated water and salt movement for irrigated wheat, cotton and sugarcane in the LCC system.

Crop	Soil	IR+R	Eciw (cm)	Rel EVT (dS/m)	Leaching fraction	Fractional change in root profile salinity
wheat	SaL	38.9	2.1	1.0	0.47	–0.58
wheat	SaL	38.9	2.5	1.0	0.47	–0.58
wheat	SiL	38.9	2.1	0.99	0.28	–0.35
wheat	SiL	38.9	2.5	1.0	0.28	–0.24
wheat	CIL	38.9	2.1	1.0	0.02	–0.24
wheat	CIL	38.9	2.5	1.0	0.02	+0.46
cotton	SaL	66.4	2.1	1.0	0.26	+0.20
cotton	SaL	66.4	2.5	1.0	0.26	+0.39
cotton	SiL	66.4	2.1	1.0	0.04	+0.80
cotton	SiL	66.4	2.5	1.0	0.04	+0.80
cotton	CIL	66.4	2.1	1.0	0.18	+0.57
cotton	CIL	66.4	2.5	1.0	0.17	+0.89
cane	SaL	109.9	2.1	0.85	0.21	+0.03
cane	SaL	109.9	2.5	0.85	0.21	+0.22
cane	SIL	109.9	2.1	0.72	0.09	+1.26
cane	SIL	109.9	2.5	0.72	0.09	+1.74
cane	CIL	109.9	2.1	0.74	0.23	–0.50
cane	CIL	109.9	2.5	0.74	0.23	+0.53

Notes: R = Rainfall
IR = Irrigation
ECiw = Electrical conductivity
EVT = Evapotranspiration
SaL = Sandy loam
SiL = Silt loam
CIL = Clay loam

It is immediately observed that the actual leaching fractions for wheat and cotton in sandy loam are greater than that in either the finer textured silt loam or clay loam soils. In the cases of cotton and sugarcane, the leaching fraction is smallest in the silt loam. The change in profile salinity, expressed as the ratio of profile salinity before and after the growing season, varies according to the salinity of the irrigation water and the leaching fraction. The largest increase in profile salinity takes place in sugarcane

grown on silt loam with irrigation water of 2.5 dS/m, i.e., an increase of 1.7 times in a single season. Another important observation is that leaching is far more effective for wheat during the cooler rabi season — leading to a decrease in profile salinity for most of the modeling combinations — than for crops grown during the hot kharif season, even though monsoon rainfall exceeds that from winter rains.

It would be interesting to know how long it would take to bring farmers' fields at tail ends of distributaries and watercourses back to acceptable salinity levels by irrigation with canal water only, or with a mixture of canal water and tubewell water. We have been unable to address this important issue through modeling as yet, because the model requires further modification so that some adverse effects of long-term irrigation with saline water can be considered, e.g., degradation of soil structure and reduction of hydraulic conductivity. Nevertheless, at this juncture, it is reasonable to assume that so long as the soil structure is not affected, the build-up of profile salinity is reversible and reclamation should not take much longer than it took the salts initially to accumulate in the profile. However, where clay migration in the profile has led to compacted layers and sharply decreased hydraulic conductivities, the reversal process will be very slow.

CONCLUSIONS: IRRIGATION MANAGEMENT IMPLICATIONS

The foregoing analysis and discussion of a large body of measured and observed data confirm the existence of a disturbing pattern of increased salinity-related problems in irrigated agriculture as location changes in the surface irrigation system with increasing distance from the head of both distributary channel and watercourse commands. The source of salt accumulation in the crop root zone of soils is the tubewell water of doubtful quality used by farmers for irrigation. Serious and persistent inequity in the distribution of high quality canal water within distributary commands, which is also mirrored at the watercourse level, has meant that farmers in middle- and tail-reach locations have become increasingly dependent upon pumped groundwater to meet the bulk of their crop water requirements. For reasons that are not well-understood at this juncture, the quality of groundwater pumped by tubewells generally decreases within distributary command areas from the head to the tail. Farmers in the tail areas therefore face a double handicap: they receive a far smaller proportion of their share of canal water than do farmers upstream along the same distributary, especially in the head reach, and the groundwater in these locations, which must be used to obtain any crop, is of poorer quality than elsewhere.

It is well-known that the sustained use of poor quality irrigation water without adequate leaching of salts from the root zone has important consequences for the long-term productivity of irrigated agriculture. This is likely to be one reason for generally lower crop yields observed in our sample areas, although no attempt has been made to relate actual crop yields with either the presence of salts in the root zone profile or the salinity of irrigation water. Because there are many other potential reasons for the low yields of agricultural crops in Pakistan, a separate program of targeted field

research by an appropriate specialized national organization is needed to quantify the effects of salinity in this respect.

It should be realized that irrigated agriculture can successfully use water for irrigation that is more saline than that found in the command area of Mananwala and Pir Mahal distributaries. However, that would require mixing saline water with better quality canal water for irrigation, at least during germination and other sensitive crop growth stages, or changing production to more salt-tolerant crops (e.g., fodder crops) or agroforestry, or adopting some combination of these two approaches. Recent examples of the reuse of drainage water for irrigation illustrate the potential use of brackish waters (e.g., see the recent review by Westcot 1988).

Theoretically at least, mixing canal water and tubewell water for irrigation is a feasible alternative for farmers. But the problems faced by farmers attempting to do so, as well as the attendant management implications, are well-illustrated in the following examples which draw upon the "real world" conditions of irrigated agriculture in the sample areas of our studies. During peak months, canal water constitutes about 28 percent of the total water used in agriculture in the sample areas. For a tubewell water quality of 1.8 dS/m (the median EC value of the entire Mananwala tubewell water quality sample), and 0.4 dS/m for canal water, mixing in the ratio 0.72 : 0.28 produces an average water quality of about 1.4 dS/m. It will be immediately noted, however, that this average EC value is still in the range of waters now recognized as being unsuitable for irrigation without mixing with better quality water. Moreover, the actual quality of the mixed water becomes worse toward the tail-end distributary commands, because of the decreasing proportion of canal water to pumped groundwater that can be mixed, and the increasingly poorer quality of groundwater in the mix.

Therefore, assuming no significant changes in current cropping patterns, management interventions with the objective of bringing the average EC value of the mixed irrigation water available to middle and tail watercourse commands below 1 dS/m, for instance, seem certain to require, and must somehow produce, greater quantities of canal water for mixing than are presently available at these locations. That is a formidable challenge, but management opportunities do exist to greatly improve the current pattern of equity in distribution of canal water at the distributary level as, for example, was demonstrated by previous IIMI/PID action research on selective canal maintenance (Vander Velde and Bhutta 1989; Vander Velde 1990). However, present conditions of distributary system performance also reflect the increasing failure of existing institutions to observe and enforce long-standing rules and procedures of irrigation system operations and administration in Punjab. That situation raises critical institutional issues that require both carefully designed and sensitively implemented research before a fuller range of appropriate management responses can be developed with potential to restore water distribution equity conditions to acceptable levels. Unfortunately, as the following more extreme example illustrates, the amounts of water made available through such efforts, will probably be insufficient to meet mixing requirements.

Since the median EC value of tubewell water in the head reach of the Mananwala Distributary is less than 1 dS/m, farmers there could rely completely upon tubewell water to meet the needs of irrigated agriculture without changing their current crop mix or incurring secondary salinity problems. In such a hypothetical situation, all canal water would then be available for mixing in middle- and tail-reach watercourses. In order to produce an average EC water quality value of 1.04 dS/m for middle-reach farmers, 36 percent of the canal water now available would be required for mixing in. However, the remaining 64 percent of canal supplies would, when mixed with available groundwater, result in an average EC water quality value of only 1.23 dS/m for tail-reach farmers. Thus, given the comparatively low proportion of canal water currently available and used in meeting irrigated agriculture requirements during peak consumption months, it is still not possible to bring irrigation water quality to within acceptable limits throughout the entire canal command area, even if head-end farmers were to use no canal water at all! The fact that average water quality during peak periods remains above 1 dS/m in part of the command area may not be harmful, provided, of course, that in other months of the year water quality is below the harmful limit and salts can be leached from the soil profile. Unfortunately, there is no evidence from current irrigation practices that this conditionality can be or is being met.

Changes in cropping patterns, as suggested above, may also be a means of sustaining agricultural production with poor quality irrigation water. So far, we are unaware of any systematic research that has focused upon farmers' responses to the adverse effects of poor quality water supplies and secondary salinity. Johnson (1990) has reported higher proportions of cropped areas under rice and sugarcane, and smaller areas under vegetables and orchards in holdings irrigated with tubewell waters of more than 1 dS/m in the Lagar command area. This finding, and our field observations elsewhere, confirm that farmers are aware of the harmful effects of prolonged irrigation with poor quality tubewell water. Hence, it is conceivable that farmers are already deliberately responding to these conditions through changes in their cropping patterns. Whether or not a productive irrigated agriculture can be sustained through such changes is a subject that requires both monitoring and continued evaluation of several dependent variables — including aquifer discharge and recharge, groundwater quality, and canal system performance — for which effective institutional mechanisms do not yet exist.

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CHAPTER 9

Application of Mathematical Models for Simulation of Canal Operations at Kirindi Oya, Sri Lanka: Preliminary Results

Hilmy Sally and Jacques Rey

INTRODUCTION

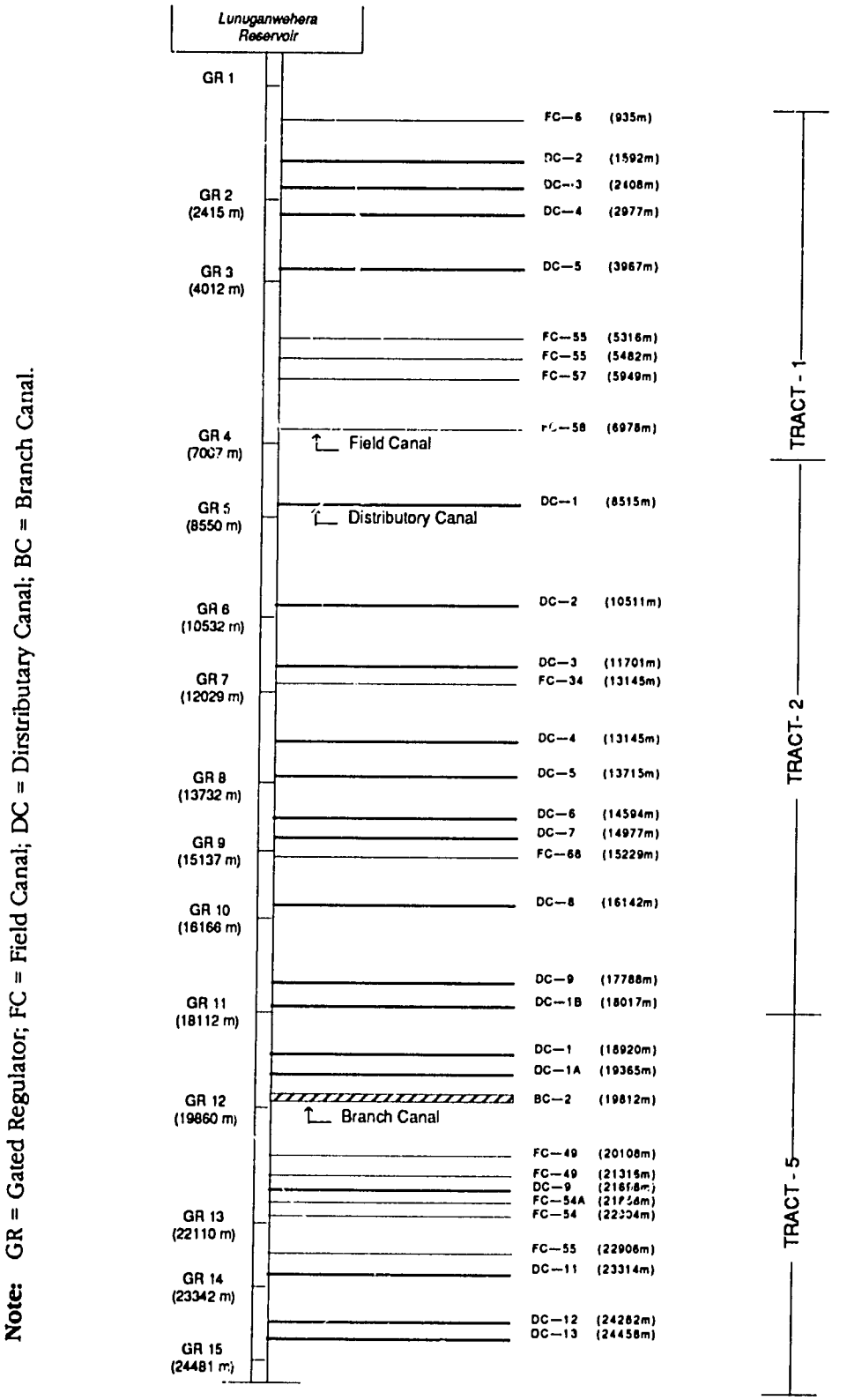
A NUMBER OF mathematical models are currently available for studying the hydraulics of rivers and canals. Models have also been developed for the automatic regulation of irrigation systems in real time. Compared to these models, the innovative feature of the mathematical flow simulation model of the Kirindi Oya Right Bank Main Canal (RBMC) is that it provides new opportunities for studying manually operated irrigation systems. In fact, the development and application of the RBMC flow simulation model constitutes the first stage of a research program intended to be of regional scope. The overall objective is to demonstrate the feasibility of using simulation models as decision-support tools for improved performance of manually operated irrigation systems.

Phase I of the Kirindi Oya RBMC simulation model project consisting of software development, field calibration of the model, and production of a comprehensive set of manuals was completed in 1990. IIMI's partners in implementing this project were CEMAGREF,[55] France and the Sri Lanka Irrigation Department (ID). Partial funding support was provided by the French Ministry of Foreign Affairs. This was supplemented by substantial contributions in terms of staff time from IIMI and CEMAGREF.

This paper presents the first results of using the Kirindi Oya RBMC model to formulate appropriate operational responses to some typical canal management problems, identified in consultation with the canal managers themselves. The material presented in the paper draws on unpublished internal reports as well as documents presented to the Study Advisory Committee, the Sri Lanka Consultative Committee, and IIMI technical staff seminars. The results should however be considered indicative at this stage in the sense that they have yet to be implemented and evaluated in the field. Comprehensive field-testing of the simulation model as a decision-support tool in

[55] Centre National du Machinisme Agricole, du Génie Rural, des Eaux et des Forêts.

Figure 9.1. Issue tree diagram of the Kirindi Oya Right Bank Main Canal.



Note: GR = Gated Regulator; FC = Field Canal; DC = Dirstributary Canal; BC = Branch Canal.

canal operations will be carried out under Phase II of the project which began in February 1991.

KIRINDI OYA RIGHT BANK MAIN CANAL (RBMC)

The Physical Context

The RBMC was developed as part of the Kirindi Oya Irrigation and Settlement Project in southern Sri Lanka (Figure 10.2 on p.209). The principal objectives of the project are: (a) the augmentation of water supplies to the existing irrigated areas covering around 4,500 hectares (ha), and (b) the settlement of over 8,000 families in the newly developed irrigated command area of around 8,400 ha. The RBMC itself was intended to irrigate about 5,000 ha of land. The development of about 3,650 ha (consisting of Tracts 1, 2, 5, 6, and 7) has been completed to date. But only the 2,743 ha of Tracts 1, 2 and 5 have ever been irrigated; Tracts 6 and 7 received irrigation water for the first time in 1991.

The RBMC takes off from the Lunuganwehera Reservoir (198 million m^3 active storage capacity). The canal is 32 kilometers (km) long and unlined with a design bed slope of 3 in 10,000 (30 cm per km). It was designed to carry a discharge of 13 m^3/s at its head but this value rarely exceeds 7 m^3/s under present operating conditions.

The RBMC model presently covers only the first 25 km of the main canal encompassing Tracts 1, 2 and 5. A total of 33 distributary and field channels take off directly from the main canal in this 25-km length (see issue tree in Figure 9.1). The offtakes are gated and of the undershot type. The downstream water level is controlled by weirs (either sharp-crested or broad-crested) that also serve as flow measuring devices (Figure 9.2). The broad-crested weirs are of fairly recent origin, having been constructed in place of the original sharp-crested weirs that were often found to be functioning under submerged flow conditions.

The RBMC is further characterized by the presence of 14 gated cross-regulators for water level control. The regulators are made up of a set of movable undershot gates (ranging in number from 5 at the head, to 2 at the tail) and a couple of lateral sidewalls (Figure 9.3).

The Operational Context

The managing agency in Kirindi Oya is the Sri Lanka Irrigation Department (ID). A succinct view of the organizational chart of the project is shown in Figure 9.4. Water management activities are under the responsibility of a Senior Irrigation Engineer (SIE). Main canal operations are centered on maintaining full supply depth (FSD), corresponding to the crest level of the sidewalls, at each of the cross regulators. Gate operators attempt to achieve the target levels by adjusting the openings of the regulator

Figure 9.2. Offtake.

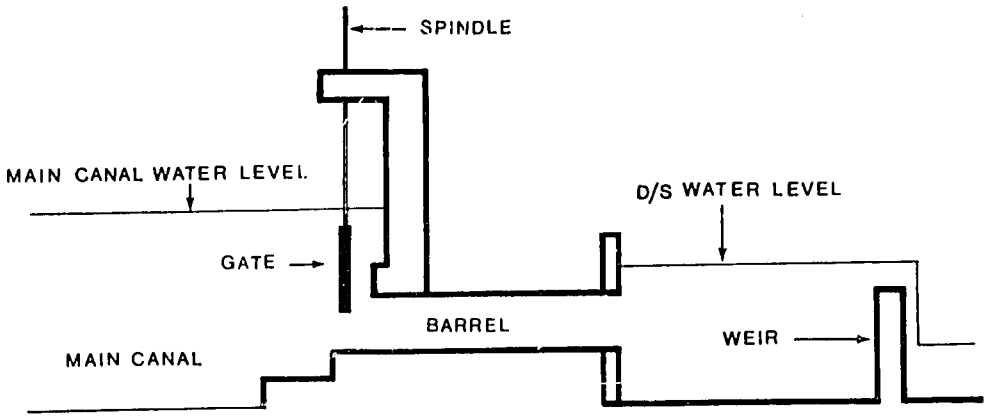


Figure 9.3. Cross-Regulator.

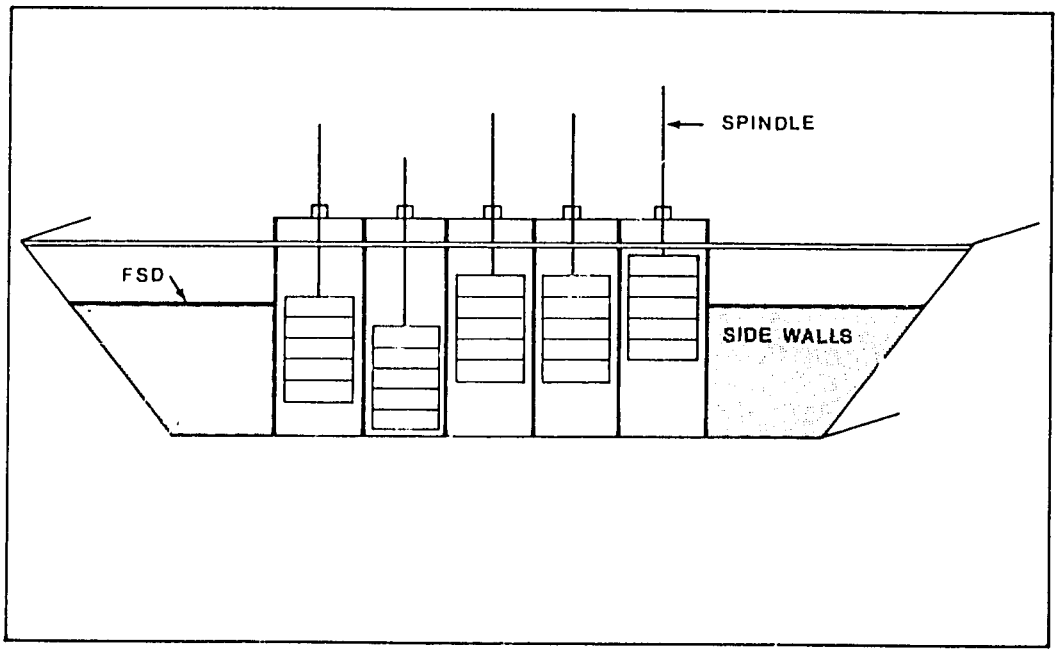
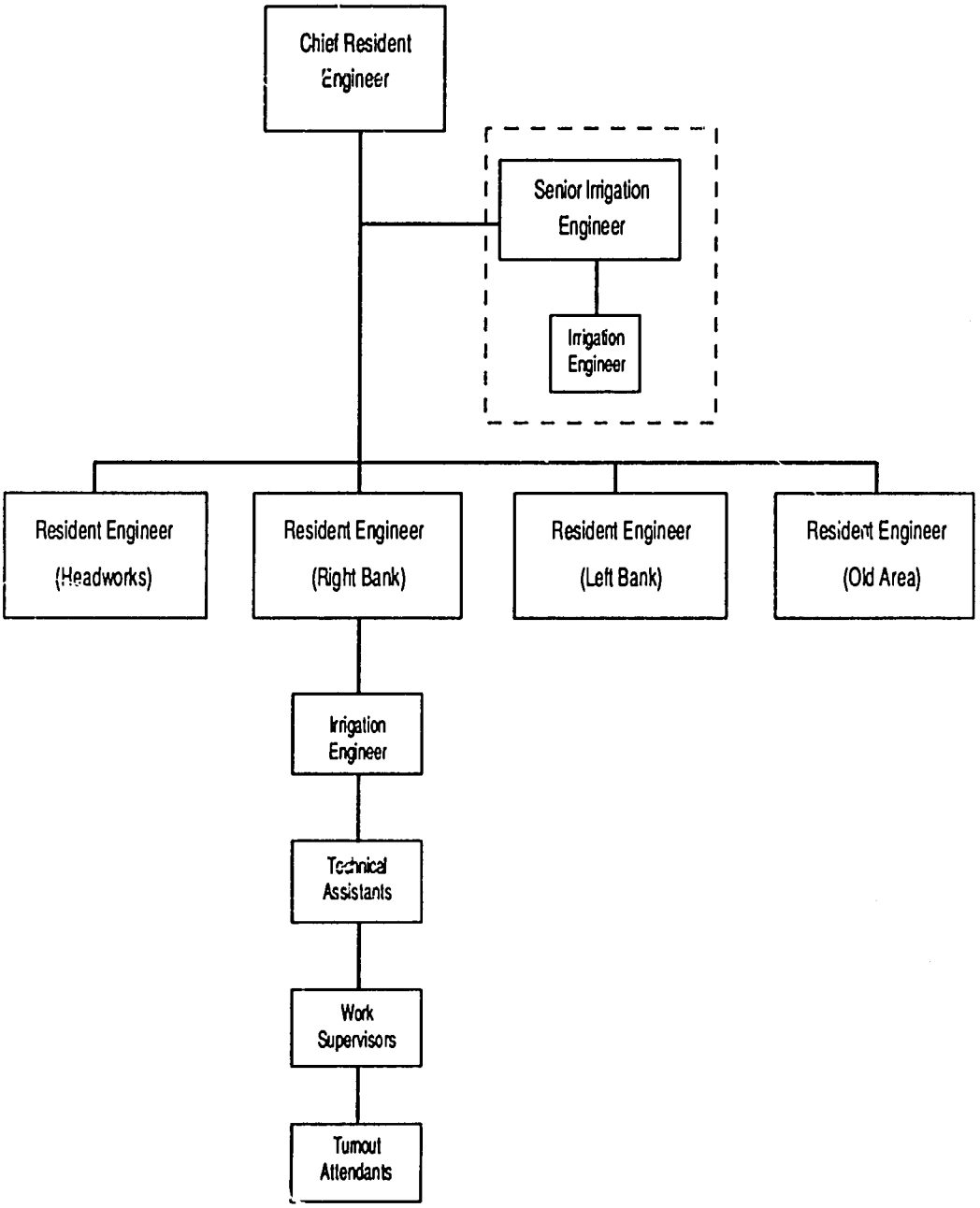


Figure 9.4. Organizational chart of the Kirindi Oya Irrigation and Settlement Project.



gates. A cross-regulator operator usually has the added responsibility of operating a certain number of offtake gates (along the main canal as well as along nearby secondary or tertiary canals). The objective here is to deliver target discharges, assessed by means of the measuring devices located at the heads of these canals.

Even though the operational objectives are fairly well-defined, the operational plans to actually attain these objectives are less-evident, especially at the cross-regulators. Ad hoc, uncoordinated interventions at the regulators give rise to instabilities in canal water levels which in turn could result in inequitable water distribution. This problem assumes even greater significance given the chronic water-short situation of the Kirindi Oya Scheme. Indeed, double-cropping throughout the scheme has not been achieved, and crop failures due to curtailment in irrigation supplies have occurred. Furthermore, the original plan to extend the command area to include Tracts 3 and 4 has been abandoned.

In this context, there is a lot of scope for greater efficiency in water distribution through improved main canal operations.

Constraints to effective main canal operations have been identified in the course of this present research project as well as in other studies conducted in Kirindi Oya, covering aspects such as:

- the impact of design on the management and performance of the main canal (IIMI, 1989),
- irrigation systems management with a view to crop diversification (IIMI, 1990), and
- management decision-making processes (Nijman, 1991).

The lack of a suitable decision-support tool makes it difficult for the SIE in charge of water management to formulate appropriate system-wide operational strategies. This situation is exacerbated by inadequate information transfer procedures. Operators could therefore sometimes unknowingly carry out local operational interventions which are not only unnecessary but which may also create perturbations that give rise to instabilities in canal water levels throughout the system. Malaterre (1989) showed that too frequent gate adjustments at a single regulator to maintain the water level within ±2 cm of FSD could result in oscillations in the water surface profile with amplitudes as high as 19 cm in some locations.

The difficulty in formulating hydraulically optimum strategies for routine operations is compounded when confronted with exceptional operational situations such as, (a) reestablishing steady state in the canal following deviation from the target condition, (b) filling of the canal, and (c) responding to rainfall.

PRINCIPAL FEATURES OF THE RBMC SIMULATION MODEL

The RBMC software is designed to run on an IBM PC-AT or PS/2 compatible microcomputer under the MS-DOS operating environment. A mathematical co-processor and EGA monitor are required. Graphics output capability on HP compatible plotters is also available.

The model is menu-driven and includes user-friendly interfaces to allow the canal manager as well as the researcher to quickly simulate a variety of hydraulic design and management configurations on the canal. The user also has access to an on-line help procedure while running the model.

The model consists of three software units that can be run either independently or sequentially:

1. A *Topography Unit* for the input and verification of the topographic data of the canal; it creates the topography files needed to run the computational programs of the steady and unsteady flow units.

2. A *Steady Flow Unit* that computes the canal water surface profile for any given combination of offtake discharges and cross-regulator gate openings; the user can also impose a target discharge at each offtake and reference levels at the cross-regulators and the model will compute gate openings along the canal; it also generates the initial hydraulic conditions for running the unsteady flow unit.

3. An *Unsteady Flow Unit* that simulates the transient flow conditions occurring in response to changes in the water supply or demand, or due to operations at the headworks and/or control structures; the user will be able to identify the best way to move from an initial water distribution plan to a new plan; the efficiency of different operational strategies can be evaluated through a set of performance indicators that integrate information on water delivery, either at a single offtake or at all the offtakes. Two types of indicators have been defined: (a) volume indicators, and (b) timeliness indicators.

Units 2 and 3 generate numerical as well as graphical outputs. The graphical outputs in particular can be used as training material for canal managers and irrigation professionals to study the hydraulic behavior of main canals.

MODEL CALIBRATION AND VERIFICATION

The reliability of model results largely depends on the quantity and quality of the input information used to describe the physical and hydraulic features of the real system. Calibrating the model to reflect the field conditions as accurately as possible is an essential prerequisite to carrying out meaningful applications of the model.

The physical information required includes (a) a longitudinal profile of the canal bed, (b) cross sections of the canal at suitable intervals to capture all hydraulically significant features, and (c) the locations and dimensions of all cross-regulators, offtakes and other singularities along the canal. The physical information was gathered in the course of a topographical survey.

The hydraulic information includes (a) roughness coefficients for the different reaches of the canal, (b) head-discharge relationships and discharge coefficients for the offtake and regulator gates, and (c) seepage losses along the canal. The values of these parameters were estimated in the course of a number of field measurement

campaigns, the first of which is described in Sally et al. (1989).

Verification (by comparing field observations with model generated outputs of water levels and discharges) and subsequent updating of the hydraulic parameters (and, less frequently, the topographical information) as needed are an integral part of model maintenance. This ensures that the model continues to yield realistic results.

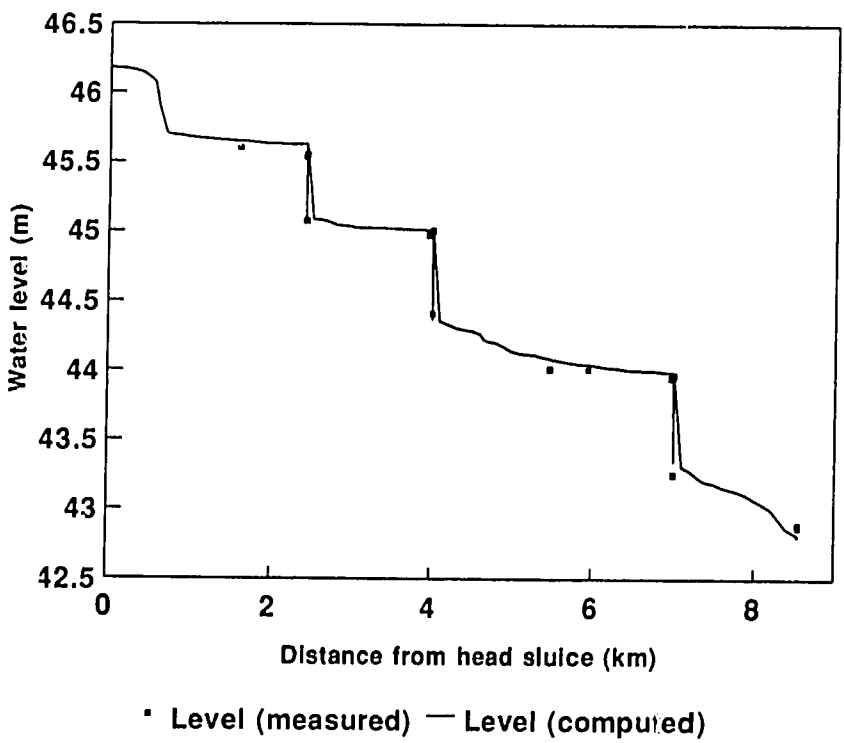
Field observations carried out during the *yala* (or dry) cultivation season in 1990 under both steady and unsteady flow conditions have highlighted the good predictive capability of the model with the present set of hydraulic parameters. (As an example, Figure 9.5 compares model output with field measurements on 29 June 1990.)

The values of these hydraulic parameters are:

Offtake (undershot) gate discharge coefficient	=	0.60
Cross-regulator gate discharge coefficient	=	0.48 - 0.60
Cross-regulator sidewall discharge coefficient	=	0.40
Strickler coefficients = 25-35 (i.e., Mannings n	=	0.04-0.029)
Seepage losses estimated at 26 l/s/km (average).		

The model also has the flexibility to accommodate different values of roughness coefficients and seepage loss per reach, if necessary (e.g., different values associated with "cut" and "fill" sections of canal).

Figure 9.5. Comparison of model output and field measurements of water level in Tract 1 (29 June 1990).



MODEL APPLICATIONS AND FIRST RESULTS

Field experimentation on live irrigation systems to identify innovative operational practices is seldom feasible — people and crops could be adversely affected. In addition, understanding the hydraulic behavior of the entire canal, especially during unsteady flow conditions, is quite difficult, given the presence of a number of regulating devices and the strong interdependency between the reaches. Most of the time, canal managers are thus unable to formulate optimum operational strategies as they are not in a position to foresee the impact of their decisions.

This dramatic lack of knowledge about system behavior can be reduced by using the simulation model as a decision-support tool. The impact of any planned intervention can be assessed prior to implementation in the field. Inadequacies in the current management response can be detected and quantified. Proposals for improvement can in turn be studied with the support of the model. Those which are compatible with the existing operational environment (i.e., physical infrastructure, staff, communication facilities, etc.) may then be selected for field implementation and evaluation.

In this chapter, the results of applying the Kirindi Oya RBMC model to address some typical operational problems that reflect, to a large extent, the concerns expressed by the ID operations staff are presented. We shall conclude this chapter with some applications of the model for design verification, which were again carried out at the request of the Irrigation Department.

The interaction with ID field staff, the ultimate end users, in planning and carrying out these simulations has been extremely rewarding. The impact of the model from the training perspective should be emphasized. The ID staff truly appreciate the fact that the simulation model helps them to enhance their knowledge of the hydraulic behavior of the canal and now recognize the range of possibilities afforded by the model to identify effective and responsive main canal operational practices.

Determining Offtake and Regulator Gate Settings to achieve Water Distribution Plans

This is a direct but very powerful application of the steady flow unit of the model. It addresses the concern expressed earlier about the lack of explicit operational plans to achieve target water levels and discharges.

Canal operation parameters (water demand at offtakes, main sluice discharge, cross-regulator gate openings and/or target water levels, etc.) are set and the steady state situation is simulated. Device openings, discharges, water surface elevations and volumes are generated. The simulation results maybe visualized in numerical or graphical format. In addition, a summary of key results of operational interest is also produced in the form of an Operational Printout. This printout lists the offtake and regulator gate settings (in terms of gate openings and corresponding spindle heights) required to satisfy the simulated water distribution plan. It is therefore meant to serve as an operational guide for the canal manager.

Evaluating Impact of Interventions at Nearby Gates on Offtake Discharge

This problem will be illustrated using the distributary canal DC5 and cross-regulator GR3 of Tract 1 (see issue tree diagram of figure 9.1 for their relative locations). An example of analysis is given below: (Question/Answer)

Q. What would be the impact on the discharge in DC5 of a sudden gate opening at regulator GR3, located immediately downstream?

A. One of the gates of regulator GR3 is fully opened at 0600. The main canal level immediately begins to fall and the discharge in DC5 shows a corresponding decrease from the initial steady state value of 142 l/s. Three hours later (at 0900) the discharge is zero (Figures 9.6 and 9.7):

This simple simulation is indicative of the type of investigation that can easily be performed using the unsteady flow unit. It demonstrates the consequences of carrying out localized interventions without consideration for possible consequences at neighboring locations.

Figure 9.6. Impact of opening of neighboring cross-regulator on main canal water level near DC5.

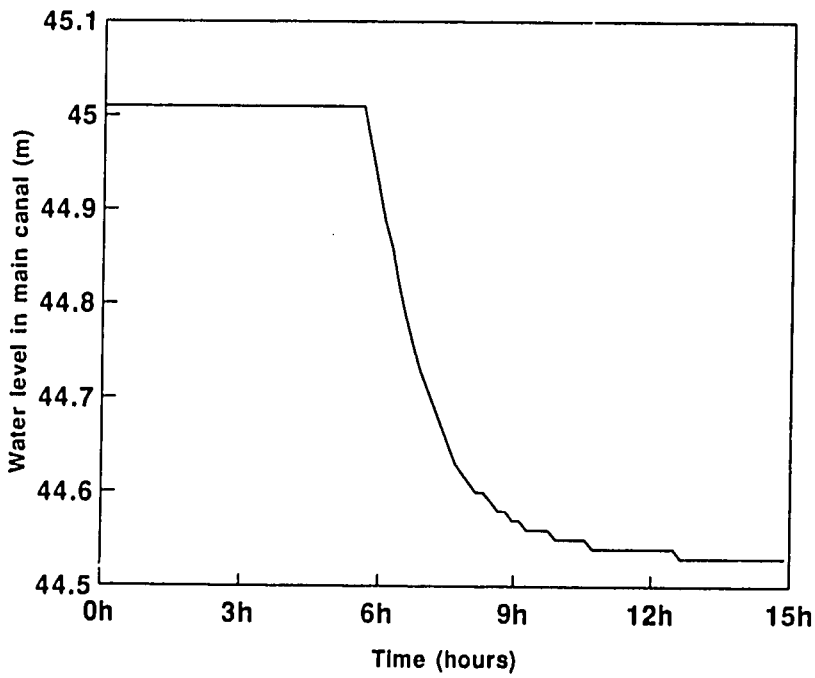
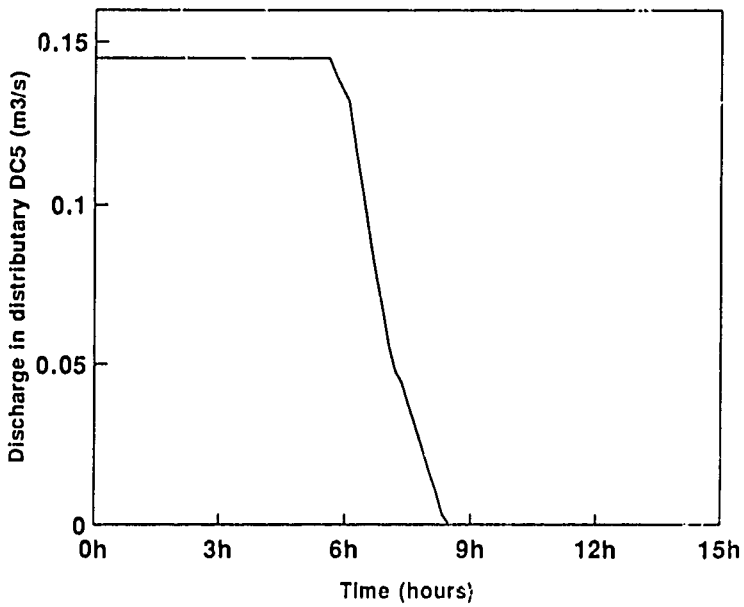


Figure 9.7. Impact of opening of neighboring cross-regulator on discharge in distributary canal DC5.



Determining Canal Filling Procedures

Canal filling is a critical operational problem that has to be faced at the beginning of the cultivation season as well as when water is reissued after a period of main canal closure (e.g., following substantial rainfall). The objective is to minimize the time taken to stabilize the main canal water level (i.e., rapidly achieve a steady state) and deliver the target discharges at all the offtakes, whilst simultaneously ensuring that the canal banks do not overtop.

The problem is to identify, both in terms of magnitude and time, suitable procedures for operating the main sluice, cross-regulators and offtakes to satisfy the above requirements. These procedures can be identified by running the steady and unsteady flow units of the model in sequence.

The field implementation essentially consists of opening the cross-regulator gates to their target values, reach by reach, once FSD is attained. The offtakes can also be opened to their target values at the same time.

The validity of a model-generated canal filling procedure was verified in the field in Tract 1 on 7-8 August 1990 (Rey 1990).

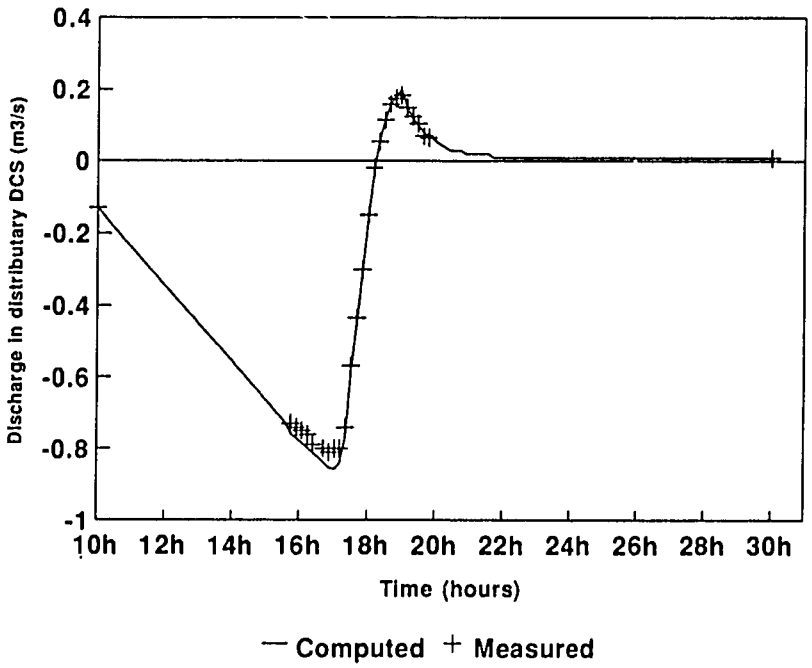
The offtakes and main sluice remained closed on 6 August 1990. At 1000 on 7 August cross-regulators GR2 and GR3 were opened so that the first two reaches of the canal were drained. In the afternoon, the main canal water level was very low. The levels upstream of the two regulators were:

GR2: (FSD-124) cm at 1520 H
GR3: (FSD-85) cm at 1730 H

The ID had scheduled an increase of the main sluice discharge to 2.8 m³/s (100 cusecs) in order to supply water to the older Badagariya system at the tail end of the RBMC. This opportunity was taken to observe the filling of the first 2 reaches of the canal and to field-test the simulation model results (magnitude of gate openings and time of intervention).

The main sluice was opened at 1520H and the regulators GR2 and GR3 closed again at 1600H and 1730H, respectively. The first reach (DAM-GR2) was filled in two and a half hours. The GR2 gates were then opened to the target values (expected to ensure FSD) after voluntarily allowing a short phase of flow over the sidewalls. FSD was achieved after sometime and a steady state was established. A similar operation was performed at GR3 and a steady state corresponding to FSD was achieved at this location as well. The filling phase of reach GR2-GR3 is presented in Fig. 9.8.

Figure 9.8. Filling phase of the reach (GR2-GR3).



The following hypothetical example is now used to demonstrate the influence of the head sluice discharge scenario on the speed of canal filling:

Tracts 1, 2 and 5 are all under irrigation. The planned head sluice release is 6 m³/s. The cross-regulators are progressively adjusted to maintain FSD. It takes over 20 hours for the discharge in the last offtake (DC13 in Tract 5) to attain its target value.

We shall now examine how water can be conveyed to the tail end at a faster rate by temporarily maintaining the head sluice discharge at a higher value than the target requirement for a certain period of time.

Figure 9.9. Water level above FSD at GR15 for different head sluice releases.

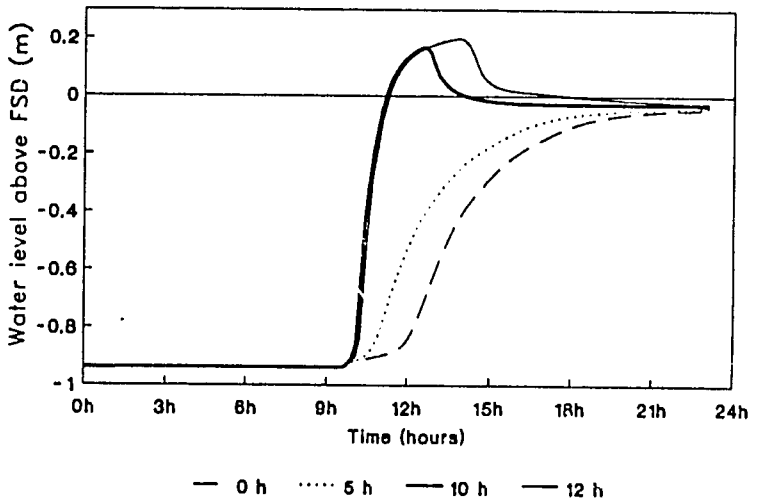
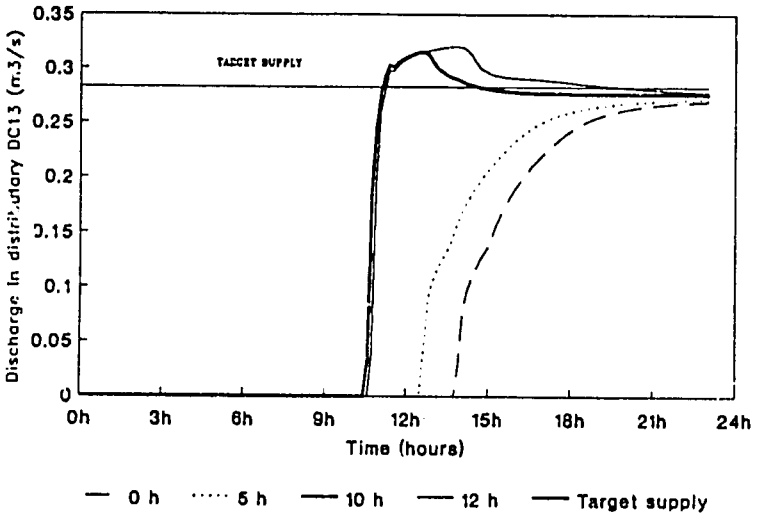


Figure 9.10. Discharge in DC13 (Tract 5) for different head sluice releases.



If the discharge is initially maintained at 8 m^3/s for a period of 10 hours, the tail-end offtake would begin to receive water 11 hours after the main sluice is opened. In addition to the reduction in the time lag for water conveyance, this approach has the added advantage that all major gate operations could be completed within the daylight hours of one day. The temporary oversupply of water can be used to fill the secondary and tertiary canals faster.

Figures 9.9 and 9.10 show the arrival time of the waves when the main sluice discharge is maintained at 8 m^3/s for 0, 5, 10 and 12 hours, expressed in terms of (a) main canal water level at cross-regulator GR15, located immediately downstream of distributary DC13, and (b) discharge in DC13 itself.

Using the Model as a Diagnostic Tool to Evaluate Water Delivery Efficiency at Offtakes

In the case of the offtakes, the operational target of the turnout attendants is to maintain a given head over the control weir located downstream of the offtake. Its value, read off a rating curve, corresponds to the target discharge for that offtake during the period in question. The required value is supposed to be achieved by trial and error adjustments to the offtake gate opening.

A number of studies (e.g., IIMI 1989 and Malaterre 1989) have highlighted the tendency for water deliveries at the offtakes to deviate from the theoretical water supply schedule in favor of an almost "on-demand" situation of satisfying farmers' requests in order that there are "no complaints." This gives rise to a basic dilemma where on the one hand, water resource constraints would seem to dictate that strict enforcement of the water delivery schedule is needed and on the other, this may lead to difficulties in the context where farmers' participation in system management is being actively sought. In hydraulic terms, ad-hoc interventions on the regulating devices could generate local closed loops that disrupt the entire functioning of the canal and which may sometimes even endanger its physical integrity.

Some of the reasons for deviations from the water supply schedule are:

- Incorrect assessment of the discharge by the operator due to inaccurate rating curve at the weir, or submerged flow conditions.

- Unexpected water-level variation in the main canal without corresponding correction of the offtake gate openings.

- Voluntary deviation from the schedule, perhaps due to:

  - a response to farmers' requests
  - a specific temporary need such as speeding up the filling of a secondary canal.

The canal manager presently lacks adequate means for diagnosing and analyzing the cause of observed deviations from the water supply schedule at the offtakes and for identifying appropriate corrective action. Diagnosis is difficult to perform without

precise knowledge of the target state of the system in terms of gate openings. Overall, the lack of reference data on the settings of the devices makes it difficult for the manager to detect anomalies in operation. In this section we shall demonstrate the use of the RBMC simulation model for these purposes (see Rey, 1990 for a detailed presentation).

The water delivery hydrograph at any offtake can be generated using field observations and the simulation model as follows:

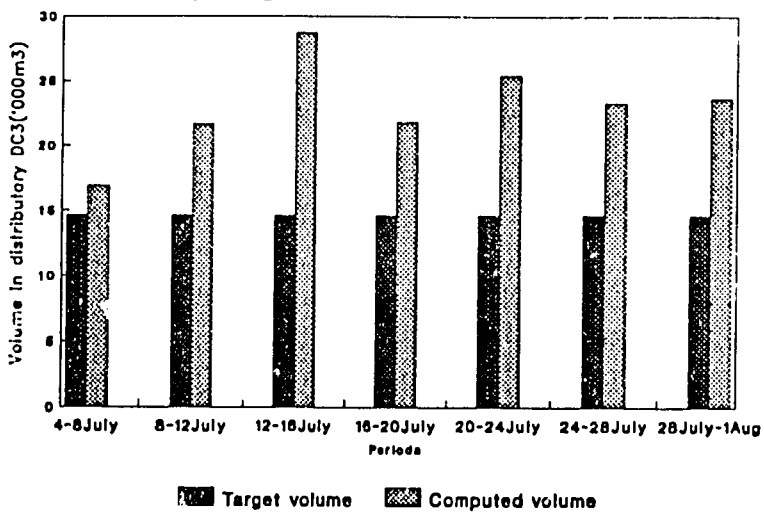
- Recording of offtake and regulator spindle heights (magnitude and time) whenever adjustments are made.
- Regular steady state measurements and verification.
- Unsteady flow simulations.

The simulations, based on observations made in Tract 1 during the month of July 1990, illustrate the use of the model as a diagnostic tool to estimate water delivery efficiency at offtakes. Distributary channels DC3 and DC5 will be used as examples.

Figure 9.11 clearly indicates the degree of oversupply to DC3 with respect to the theoretical target, computed in terms of cumulative volumes over 4-day rotational periods.

Figures 9.12 and 9.13 show some of the results of the routine field monitoring and simulations carried out on the offtakes in Tract 1 during July 1990.

Figure 9.11. Comparison of target and computed volumes over 4-day rotational periods (between 4 July-1 August 1990) in DC3 Tract 1.



The simulation model therefore proves to be useful not only to identify effective operational practices, but also for performance evaluation. Performance indicators such as Delivery Performance Ratio (DPR) and Relative Water Supply (RWS) can be computed, at one or more offtakes and over any period of time.

It was indicated earlier that sometimes there are voluntary deviations from the theoretical delivery target. Such situations can also be analyzed using the model. The discharge computed immediately after an operator's intervention is considered to represent the operators' discharge target, which could be different from the theoretical target.

Figure 9.12. Discharges in DC5, Tract 1 (28 July-1 August 1990).

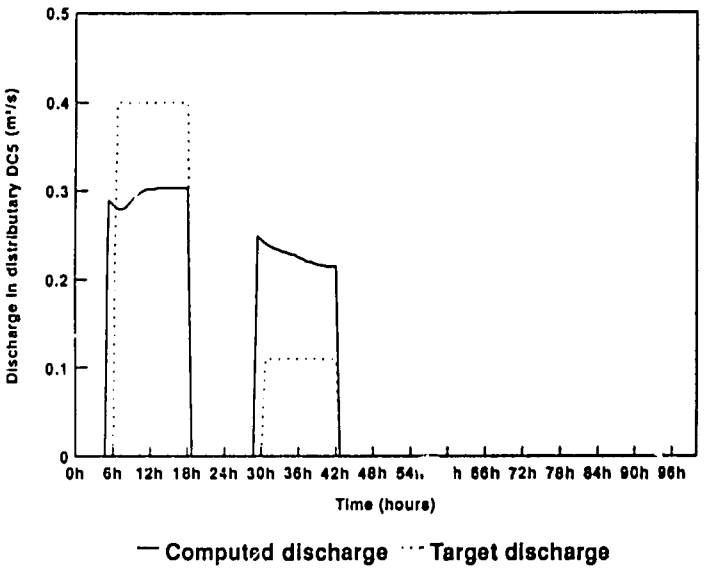
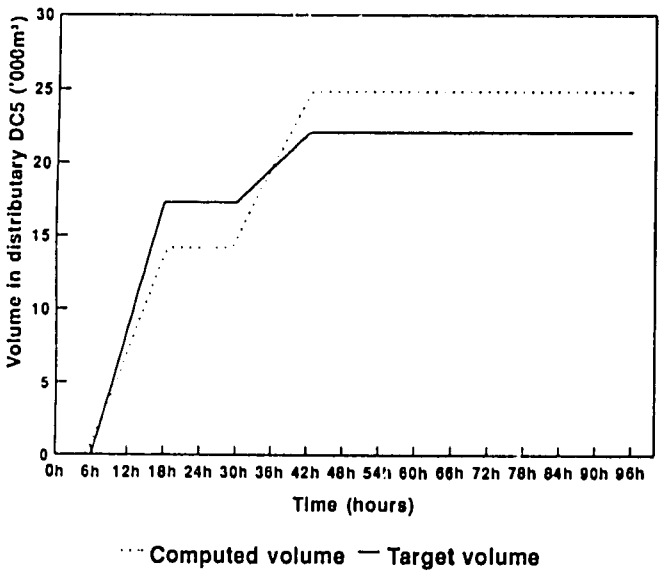
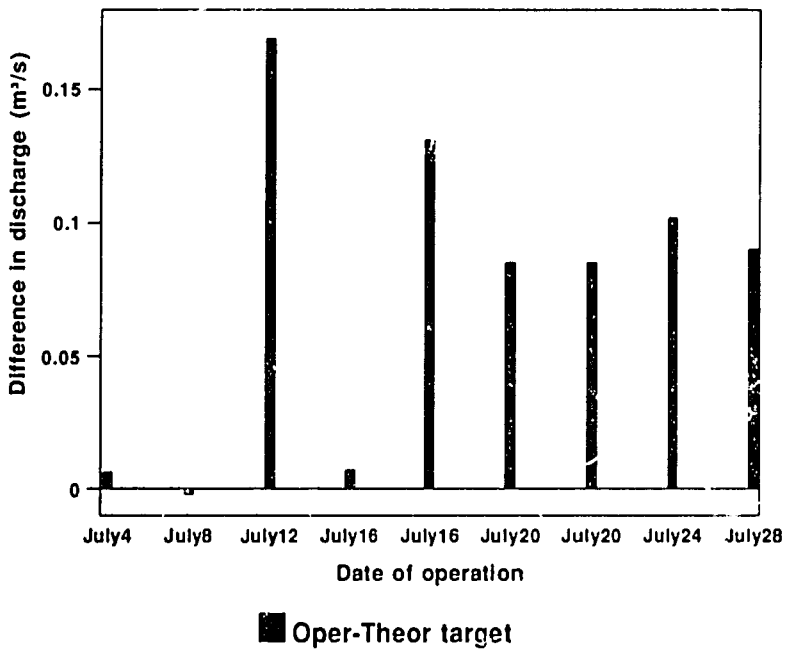


Figure 9.13. Volumes in DC5, Tract 1(28 July-1 August 1990).



Comparing the values of these two targets, as in Figure 9.14 will bring to light the existence of voluntary deviations. Figure 9.14 indicates that the operator's interventions on 4 July, 8 July, and 16 July resulted in his achieving the theoretical target discharge. The oversupply observed on the other days could be because the operator is responding to farmers' requests for water, which are usually more than the scheduled discharge. Investigations to identify the underlying causes could include verification of the weir rating curve, reconsideration of the water requirement computation assumptions, etc.

Figure 9.14. Deviation from theoretical target by gate operators at DC3 Tract 1 (4 July-1 August 1990).



Responding to Rainfall

Given the critically water-short context of the Kirindi Oya Project, ID staff often expresses the view that one way of economizing water use is through better use of rainfall. Rainfall in the project area exhibits considerable spatial variability. A precondition for implementing a strategy to respond to rainfall is information transfer (on the time and quantity of rainfall) from the field to the SIE in the water management unit. Effective communication channels for conveying operational instructions, almost in real-time, from the SIE to the field are also required.

The rainfall response problem can be analyzed in two stages:

1. When rainfall occurs in a particular area, turnout attendants normally close the offtake gates. If there is no rainfall in other areas, what actions should be taken to ensure that these areas continue to receive adequate water supply? The present management response is to adjust some gates, by trial and error.

2. What should be the response when heavy rainfall occurs throughout the project area? Presently, the water issues at the offtakes and main sluice are reduced in proportion to the amount of rainfall received. If the rainfall exceeds 25 mm the main sluice discharge is reduced to about 600 l/s (which corresponds to the empirical minimum discharge required to compensate for seepage losses along the canal), and regulators are closed, the ID objective being to maintain the levels in the main canal.

The problem can thus be summarized as shut-down (partial or complete) of the canals, and start-up (canal filling). As the canal filling phase has already been dealt with, only the shut-down phase is considered here.

If the turnout attendants proceed to close offtake gates in an uncoordinated manner, the accompanying increase in main canal discharge could create dangerous oversupply or overtopping in downstream reaches of the canal. if informed of the perturbation, the SIE would be able to determine appropriate operational responses, using the model, and transmit gate adjustment instructions to the field staff.

The following example will be used to illustrate the use of the model to determine operational procedures (provided of course that effective information transfer takes place). We shall assume that only Tracts 2 and 5 are being irrigated; Tract 1 remains uncultivated.

The gates of Tract 2 are closed at 0800 on a particular day, following heavy rainfall. The resulting increase in main canal level appeared to be within an acceptable range so that cross-regulator adjustments could be avoided in this particular case. The remaining question was then: What actions should be taken to continue to achieve target discharges and volumes in Tract 5 and to divert extra flow to the tail end (downstream storage facility)? Three possible responses were formulated. They were evaluated at offtake BC2 in tract 5 in terms of the deviations of volumes delivered with respect to the targets, and of the management effort for gate operations:

Scenario 1: Using the gate-opening computation mode of the unsteady flow unit of the model, the optimum gate adjustments to continue to maintain constant offtake discharges are obtained. The objective is achieved (within ±10%) with 7 operations at BC2 (from 0900H to 1500H).

Scenario 2: The set of offtakes in the first half of Tract 5 are adjusted in a single operation at 12 noon. The rest of the offtakes are adjusted in one operation as well, at 1300.

Scenario 3: No operations are performed in Tract 5.

Figure 9.15. Scenario 1: Seven gate operations at BC2.

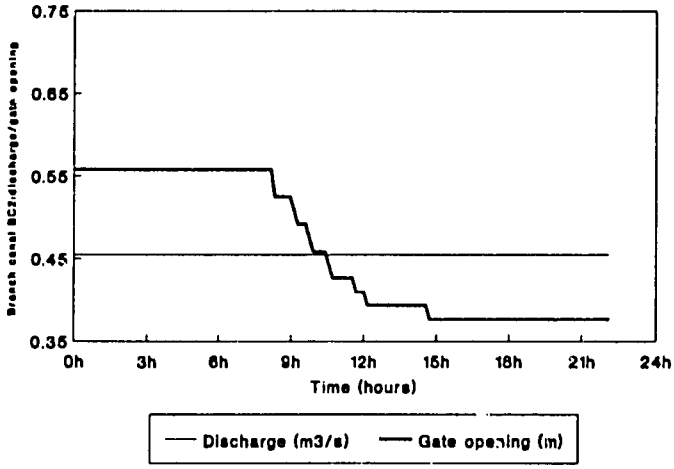


Figure 9.16. Scenario 2: One gate operation at BC2.

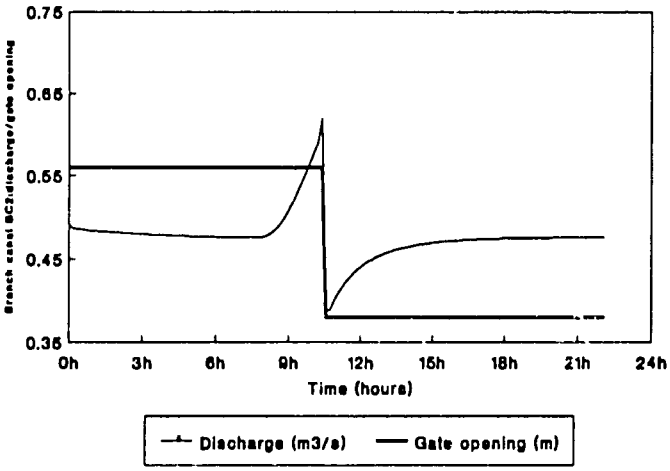
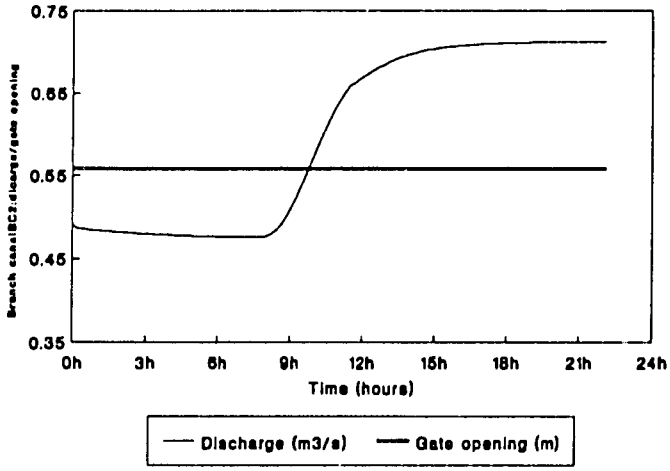


Figure 9.17. Scenario 3: No gate operations at BC2.



The results, shown in Figures 9.15, 9.16 and 9.17 indicate the following:

- If no actions are performed, more than 20,000 m^3 of water in excess of the target volume are diverted into BC2.
- Although operational scenario 1 is theoretically the most effective, it is more demanding in terms of management effort. The approximate response of scenario 2, requiring less effort, is also quite acceptable in terms of volumes. The SIE could choose to implement whichever scenario is compatible with the staffing and communication facilities at his disposal.

Effecting the Transition from One Steady State to Another

In a transient phase of functioning, there is a continuous process of evolution of the hydraulic parameters (e.g., water levels, discharges) till such time as a final steady state compatible with the imposed external conditions (e.g., main sluice discharge, gate openings) is obtained.

The management tasks in this context are then: (a) to achieve the expected final target state, and (b) to minimize the duration of the transient phase. Suitable dynamic strategies that enable the canal manager to fulfill the above tasks can be identified with the help of the unsteady flow unit of the model.

For example, consider the situation observed during one of IIMI's calibration campaigns when the main sluice discharge was 4.798 m^3/s (170 cusecs) and where only Tracts 2 and 5 were being supplied with water. Suppose that it is now required to convey an additional discharge of 1.118 m^3/s (40 cusecs) beyond Tract 5 in order to supply the small storage reservoir at the end of the RBMC.

The obvious operational intervention would be to increase the main sluice discharge by this amount.

If none of the intervening devices are operated in response to this change in main sluice discharge, only 143 l/s will arrive at the end of Tract 5 instead of the desired 1.118 m^3/s (see Table 9.1). This occurs due to the fact that the offtakes at the head are able to take more than their target discharges, thus deriving the most benefit from the increased head in the main canal. On the other hand, if appropriate adjustments were progressively made at the cross-regulators, the desired increase in discharge at the tail end of the main canal can be achieved (see last line of Table 9.1).

If one were to operate the devices to accommodate the increased main sluice discharge so that fluctuations in main canal water levels as well as in offtake discharges are minimized, the question then is to determine the time and amplitude of these operations. This information can be obtained by running the steady and unsteady flow units of the simulation model.

All operations can be completed in 5 hours and hence within a normal working day (Table 9.2).

There was no need (with one exception) to operate the offtake gates because operation of the regulators alone was sufficient to restore the main canal water level

Table 9.1. Discharges when intervening devices are not operated.

	Head	Tail	Increase at head	Increase at tail
Initial discharge (m^3/s)	4.798	0.082	-	-
Discharge after increase at head (no operations of gates) (m^3/s)	5.916	0.225	1.118	0.143
Discharge after increase at head (with operation of regulators only)	5.916	1.189	1.118	1.107

Table 9.2. The times at which the cross-regulators should be operated.

Cross Regulator	Distance from head sluice (m)	Time of operation (after head sluice) hh:mm
GR2	2,415	00:30
GR3	4,012	01:00
GR4	7,007	01:50
GR5	8,550	02:00
GR6	10,532	02:20
GR7	12,029	02:40
GR8	13,732	02:50
GR9	15,137	03:00
GR10	16,166	03:10
GR11	18,112	03:30
GR12	19.860	04:00
GR13	22,110	04:30
GR14	23,342	04:50
GR15	24,481	04:50

to the desired value to maintain discharges through the offtakes. During the period of transition, the value of one of the performance indicators (defined as the ratio between the volume delivered and the target volume) for the offtakes lies between 0.95 and 1.12, indicating that the variation in offtake discharge during this phase is negligible.

Determining Maximum Carrying Capacity of the Main Canal

The maximum carrying capacity problem is a straightforward application of the steady flow model which consists of estimating the maximum possible flow that can be conveyed in the main canal without overtopping the banks anywhere.

Figure 9.18 shows the water surface profiles between the 5- and 10- kilometer points of the canal for different values of main sluice discharges (the cross-regulators being fully opened and the offtakes closed). The overtopping that occurs around the 7-km point for higher values of discharge is clearly visible.

Once the points of the canal banks likely to overtop have been located, the amount of earthwork filling required to prevent this happening can also be estimated. Actual field verification of topography, etc., will be necessary. But the usefulness of the model is that it clearly pinpoints the likely weak sections where further field investigations should be focussed.

The absolute carrying capacity can also be computed for each different canal reach. The results obtained with the cross-regulators fully opened and all the offtakes fully closed are shown in Table 9.3.

The main canal capacity under different operational assumptions can also be studied using the steady flow unit of the RBMC model.

For example, ID water requirement computations assume peak water requirements of 2.72 l/s/ha. Under these conditions, a maximum discharge of 9.25 m^3/s can be released at the main sluice without causing the canal banks to overtop anywhere. But the water available at the tail end is now reduced to 1.46 m^3/s, which is insufficient to meet the peak irrigation requirements of the approximately 900 ha in the newly developed Tracts 6 and 7.

On the other hand, if water requirements were only 2 l/s/ha at the head of each main canal offtake, all of which are assumed to be opened, the maximum possible main sluice discharge is found to be 8.75 m^3/s. After satisfying the discharge requirements at the offtakes, about 2.85 m^3/s is available at the tail end of the canal (GR15 location). This quantity is more than adequate to meet the water requirements of Tracts 6 and 7.

Figure 9.18. Water surface profiles between the 5-km and 10-km points of the main canal for different main sluice releases.

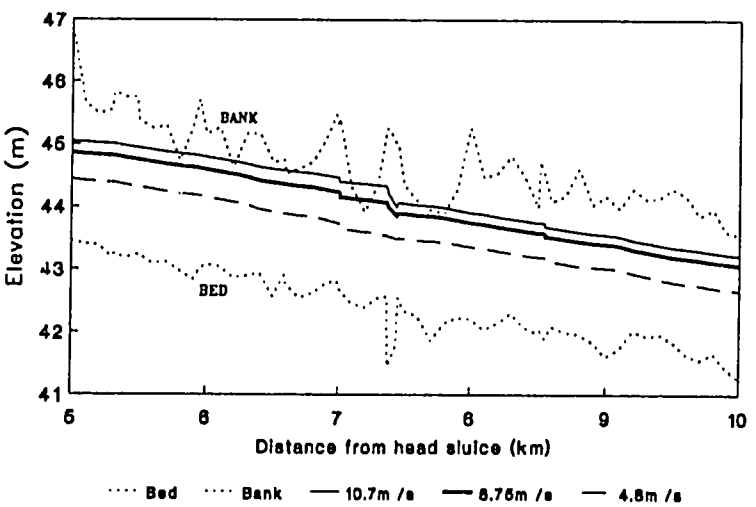


Table 9.3. Results when cross-regulators are fully opened and offtakes fully closed.

Reach	Distance (m)	Maximum discharge (m^3/s)
HS - GR2	0 - 2,415	> 11.6
GR2 - GR3	2,415 - 4,012	10.8
GR3 - GR4	4,012 - 7,007	9.3
GR4 - GR5	7,007 - 8,550	6.9
GR5 - GR6	8,550 - 10,532	> 11.4
GR6 - GR7	10,532 - 12,029	> 11.3
GR7 - GR8	12,029 - 13,732	> 11.3
GR8 - GR9	13,732 - 15,137	5.9
GR9 - GR10	15,137 - 16,166	5.9
GR10 - GR11	16,166 - 18,112	8.1
GR11 - GR12	18,112 - 19,860	6.1
GR12 - GR13	19,860 - 22,110	3.8
GR13 - GR14	22,110 - 23,342	4.9
GR14 - GR15	23,342 - 24,481	6.1

This set of simple simulations brings to light some of the design-management implications of attempting to satisfy the peak water requirements of the entire canal command at the same time (even if water resources in the reservoir permitted such an attempt). Staggered supply of irrigation water seems to be necessary. Different stagger options can also be evaluated using the model.

Impact of Canal Lining and Weed Growth on Carrying Capacity

The operating conditions used are:

1. Tracts 1,2 and 5 under irrigation with head sluice discharge of 6 m^3/s.

2. Cross-regulators set in adjustable mode to maintain FSD immediately upstream (this is the usual operating condition, irrespective of the physical condition of the canal).

Weed growth in the canal (increased roughness) was simulated by decreasing the Strickler Coefficient values by 10 (subject to a minimum value of 25) with respect to their calibrated values.

An increase in the Strickler Coefficient to 50 at every section was used to simulate a lined canal (ID estimates Manning's n of 0.018 for cement mortar lining). However, the canal cross sections were not altered in any way; in actual practice, a lined canal would have a uniform cross section. Seepage losses were also not altered, though this

too would be reduced in the case of a lined canal. The results are nevertheless indicative of what would take place if the canal was lined.

Figure 9.19 shows the variation of water surface elevation between the 5-km and 10-km points of the canal under the same set of hydraulic conditions for 3 cases: 1) the canal in its present state, 2) a weed infested canal, and 3) a 'lined' canal.

The offtake discharges are the same for the 3 cases. Actual regulator gate openings maybe different but the water level in the main canal is maintained at FSD, wherever possible.

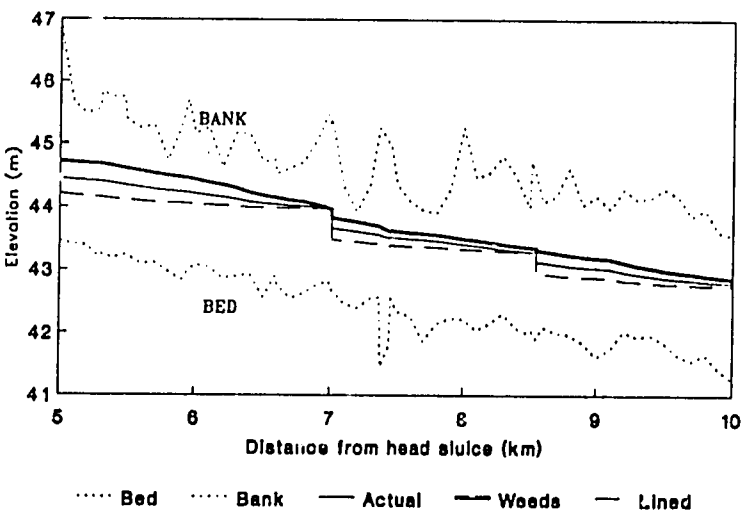
As expected, the highest water surface elevation is obtained when there is excessive weed growth. At two regulator locations, it is no longer possible to maintain the canal water level at FSD; this implies that if there is a lot of weed growth the canal banks could be overtopped even at relatively low discharges. The degree of weed growth cannot be expressed accurately in terms of a corresponding value of the roughness coefficient alone. The results are however of pedagogical interest and can also be used to orient further investigations.

The canal capacity increases by about 1.4 m^3/s for average cement mortar lining (assuming an offtake discharge scenario of 2 l/s/ha). That is, the maximum permissible head sluice discharge is now 10.15 m^3/s with a discharge of 4.25 m^3/s becoming available at the tail end.

For the weed infested canal, the maximum permissible head sluice discharge falls to as low as 7.5 m^3/s.

The importance of canal maintenance and its impact on canal carrying capacity are thus demonstrated.

Figure 9.19. Water surface profiles between the 5-km and 10-km points of the main canal for different roughness coefficients.



The potential benefits of lining the canal, at least in terms of increased carrying capacity are also shown. However, the actual benefits of canal lining would have to be assessed on an economic basis, taking into account factors such as smaller canal cross sections, less excavation, increased hydraulic radius and increased capacity, added cost of lining, different maintenance needs, etc.

CONCLUSIONS

The RBMC simulation model provides the system manager with a holistic view of the hydraulic functioning of the canal, especially useful under dynamic transient conditions. This in turn enables him to formulate coordinated canal operations strategies to respond to a variety of management situations, both routine and exceptional. Enhanced understanding of system behavior should also facilitate dialogue with farmers, eventually leading to a more productive role for them in water distribution activities.

From the point of view of IIMI's research, the Kirindi Oya RBMC simulation model provides an effective methodological approach to analyze problems related to main canal design and management. In addition, the model also serves as an innovative training tool.

This paper has highlighted some examples of the capabilities of the model to address the question of effective and responsive main canal operations. Specific applications covering routine management tasks (such as achieving a given water distribution plan) as well as exceptional events (such as canal filling and responding to rainfall) have been presented. Procedures for employing the model as a diagnostic and performance assessment tool have been outlined. Some issues pertaining to design and maintenance have also been addressed.

Extensive field-testing of the use of the model in support of practical system management is planned in the next phase of activity. IIMI's collaborator in this venture, the Sri Lanka Irrigation Department, has already manifested much interest in the potential uses of this innovative approach.

This experience in the practical use of the model will provide useful insight on the scope for computer-assisted management in manually operated irrigation systems and will probably determine prospects for extension of the methodology to other sites.

This paper has concentrated on the physical aspects of model use. However, it is recognized that there are a number of organizational implications related to the practical application of the simulation model as a management tool. Considerable improvement of the internal communication network and information transfer procedures, as well as attitudinal changes on the part of field staff will almost certainly be required if effective use is to be made of the range of possibilities afforded by the model. These aspects have not been discussed here but will constitute an integral part of the next phase of activity.

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PART 4

Towards Better Performance

CHAPTER 10

Performance of New Irrigation Settlement Schemes: A Case Study from Kirindi Oya, Sri Lanka

R. Sakthivadivel, Nihal Fernando and Douglas J. Merrey*

OUR OVERALL ANALYTICAL approach is drawn from systems theory (IIMI 1988b, 83). In a hierarchial view of an irrigation system, at the first level, it is an irrigation water conveyance and delivery system, consisting of the physical infrastructure of canals and gates, the irrigation agency personnel who operate they system and deliver water, and the farmers who receive water and grow crops. At the second level, it is an irrigated agricultural production system. The farmer, who is the producer, makes decisions, obtains credit, procures labor, combines these inputs with water and land, and finally produces the crop. He markets much of it and seeks to improve his well-being with the resulting economic benefits. At the third level, there is the socio-political-economic system in which the other two systems are embedded. The social values, beliefs an attitudes, along with the various organizations, provide the basic framework for the behavioral patterns of the system. These systems are also embedded in the wider environment with its natural, economic, social, and other dimensions.

As we go higher in the hierarchy of systems from the first level onwards, the complexity of the systems and the interactions increase, the proportion of hardware in the system decreases, and the degree of control and capacity to manipulate the system decreases.

The system has many attributes and characteristics: the scale, size and variety of the components such as the canals, structures, soils and crops; the complex interactions among water, fertilizer, crops, prices, markets and behavior patterns; the dynamic nature of the processes — no two seasons are alike; the effects of uncertainties — hydrologic, economic and political; the multiplicity of persons making decisions at

* This paper is the product of the work of many people. Dr. P.S. Rao was the project leader for this work during most of the period of implementation and contributed a lot to the research and to our own thinking about the project. Our research officers, especially P.G. Somaratne and B.R. Ariyaratne, gathered much of the data and assisted in its analysis and interpretation. Dr. Masao Kikuchi also contributed some important suggestions. The authors are extremely grateful to them and to the staff of the management agencies for their close cooperation.

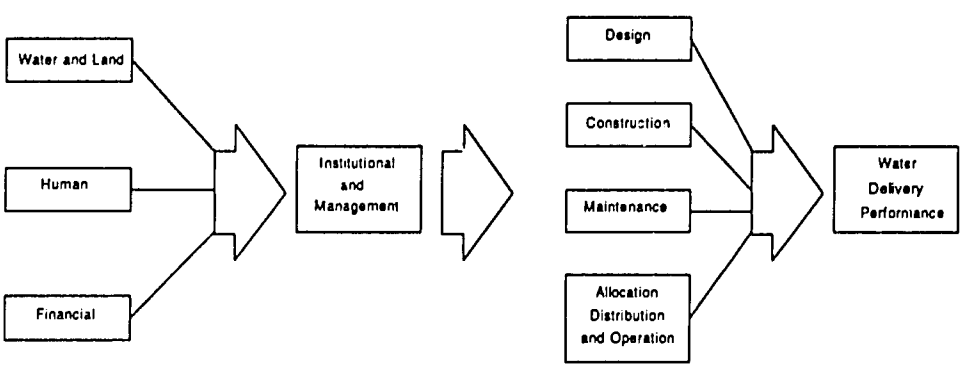
various levels; the competitive nature of resource allocation situations, especially in the context of large-scale public systems serving a large number of beneficiaries, many of them newly settled.

We use "performance" in a simple way, to refer to outputs at various levels and in various time frames. Performance is measured by comparing the degree to which the specified outputs match the specified objectives. It is important to distinguish, conceptually, "short-term performance" from "long- term performance." If managers take a short-term view, for example satisfying water users clamoring for water during a particular season regardless of the long-term implications, or maximizing short-term profit at the expense of long-term market share (as some U.S. firms are accused of doing), then the system may veer "off track" in terms of its long-term objectives and its sustainability. If the long-term objectives are the primary rationale for decisions, then very different decisions may be taken.

The performance of an irrigation project is governed by many factors, ranging from policy and planning decisions at the national level to the operation and management decisions at the farm-gate level. This paper focuses on the performance of the water conveyance and delivery system in a new irrigation settlement project. It examines the interplay between the policy, planning, and management decisions made at the national, project, and subsystem levels, and how they influence the water delivery performance of the Kirindi Oya Irrigation and Settlement Project in southern Sri Lanka. A major theme is the likely impact of decisions made to achieve short-term objectives upon the long-term sustainability of the system.

Figure 10.1 provides a schematic representation of the factors affecting the water delivery performance of a system. The water delivery performance itself is analyzed using the concepts of reliability, adequacy, and equity. The adequacy of water supply is characterized by the Relative Water Supply (RWS) parameter while equity is expressed through the Water Delivery Performance (WDP). Explanations of the observed patterns of reliability, adequacy, and equity take us back through the factors identified in Figure 10.1. Analysis of the performance of the whole project would have

Figure 10.1. Schematic representation of the factors affecting the water delivery performance of an irrigation system.



to go beyond the water delivery system, but is outside the scope of this paper, though not of our research. The water delivery system performance is crucial for the performance of the larger project.

CHARACTERISTICS OF NEW IRRIGATION SETTLEMENT PROJECTS

In many developing countries, population pressure and a desire to attain self-sufficiency in food, fiber, and shelter have led to a strategy of spreading the available resources and developmental activities very thinly among the population. This is the case in irrigation settlement projects in Sri Lanka, where many families are eligible for settlement in such projects. In many new irrigation settlement projects, some form of irrigation has already been in existence, either through diversion structures such as anicuts or through tanks. These areas are here referred to as old areas to distinguish them from the newly settled areas (new settlements) after the construction of the irrigation project.

Several unique problems of such new irrigation settlement projects can be identified. These include: water allocation conflicts between old areas and new settlements; a mismatch between assumed design and actual water requirements, especially in the early years; behavior patterns of new, often inexperienced, settlement farmers; and planning and implementation of the project by officials. These problems will be illustrated below with data from Kirindi Oya.

THE KIRINDI OYA IRRIGATION AND SETTLEMENT PROJECT[56]

Overview

In collaboration with the implementing agencies, IIMI undertook a study in the Kirindi Oya Irrigation and Settlement Project (KOISP) to identify, through field-level research, means of increasing the use of existing land, water, and infrastructure resources through improvements in the processes of design, system management, and operation and maintenance, paying particular attention to the requirements of crop diversification. The Asian Development Bank (ADB) is supporting this research. The specific objectives of the study are to identify key organizational and management factors that influence the performance of irrigation systems and the interaction between the dominant factors and selected physical characteristics of the irrigation system; and to investigate appropriate on-farm water management for diversified crop cultivation. Several reports and publications are now available on this and other IIMI research in the Kirindi Oya Project (IIMI 1988a and b; 1989a and b; 1990; Stanbury 1989; Merrey and Somaratne 1989; Sally et al. 1989; IIMI 1990).

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[56] This paper discusses the situation as of mid-1989; there have been important changes since that time, to be reported elsewhere. IIMI is research continues at present in an "action research" phase to test and adapt management innovations in close collaboration with the implementing agencies.

The Kirindi Oya Project is being developed with financial assistance from ADB, Kreditanstalt fur Wiederaufbau (KfW) and the International Fund for Agricultural Development (IFAD). The project envisages the augmentation of irrigation water supplies for the existing irrigation systems (Ellagala and Badagiriya) covering about 4,500 ha, the provision of irrigation facilities through right bank (RB) and left bank (LB) main canals from the newly-constructed Lunuganwehera Reservoir for an additional area of approximately 8,400 ha, and the settlement of about 8,320 families on the newly irrigated lands (Figure 10.2). Increasing food production for the country and providing employment through the settlement of landless people are important national objectives.

Under Phase I of the project, the reservoir at Lunuganwehera was commissioned in early 1986, and new and improved irrigation facilities were provided for 8,775 ha, of which 4,584 ha were already under cultivation with existing tanks supplied through an anicut. Phase II construction, with ADB financial assistance, commenced in 1987 and is intended to develop an additional 4,100 ha of new land.[57] The phasing of the project was necessitated by large cost overruns and time delays, forcing the Government of Sri Lanka to seek additional assistance from the ADB.

The climate of the project area is tropical and is characterized by year-round high temperatures (26° to 28°c). Evaporation is uniform throughout the year, with an annual average of 2,100 mm/year. Mean annual rainfall is 1,000 mm; the *maha* season (October to February) rainfall is approximately three times higher than the *yala* season (March to August) rainfall. Soils in the project area consist of well-drained reddish brown soils (RBE) in the upland and intermediate zones, and poorly drained low humic gley (LHG) soils in the lowland areas. Annual water availability per hectare is in the order of 2.3-2.6 m/ha. Compared with other settlement schemes in Sri Lanka, for example Mahaweli System B with an annual availability of about 3.2 m/ha, this is

Table 10.1. Recommended cropping pattern for KOISP.

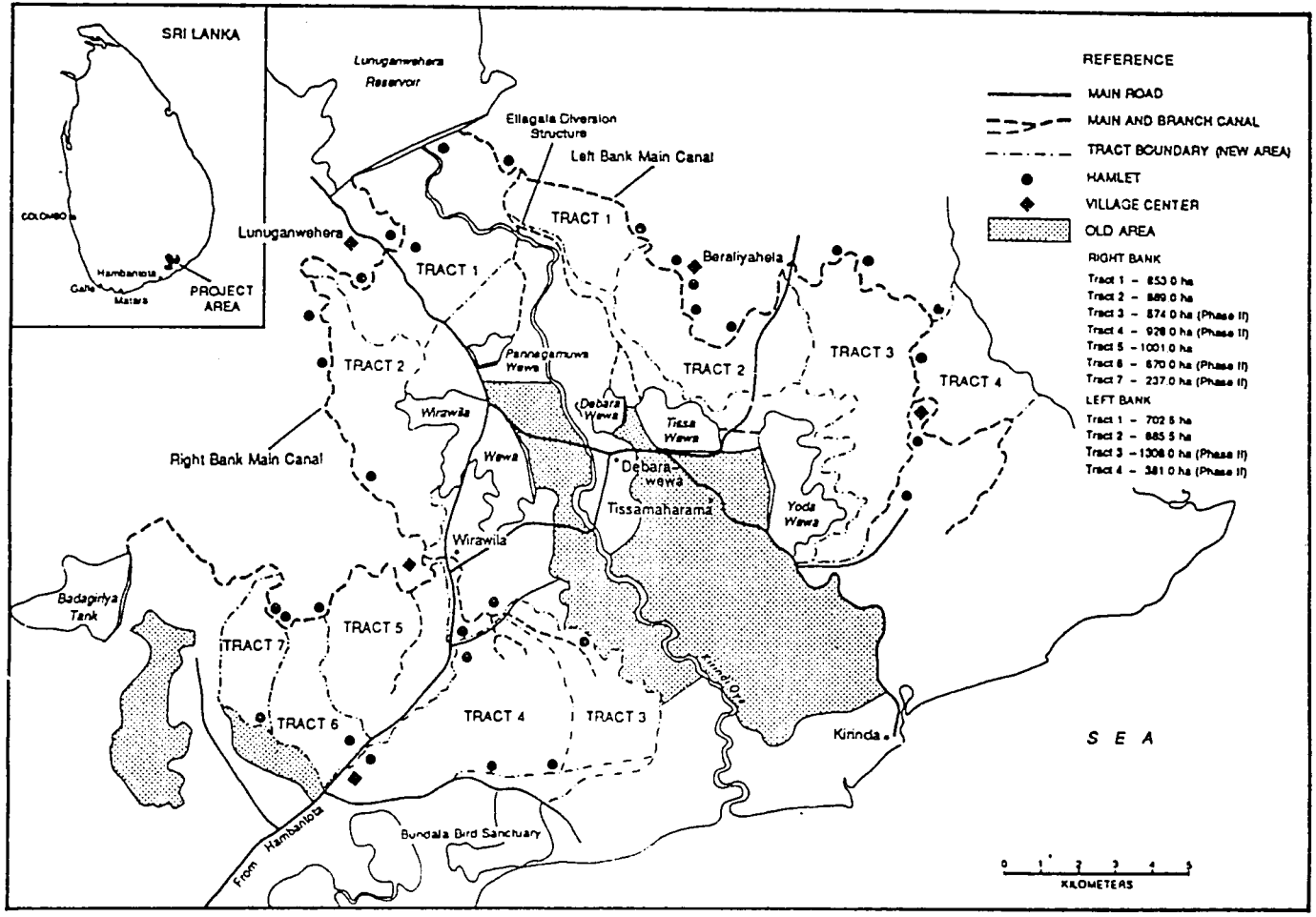
Soil type	Maha season	Yala season
Lowland	100% rice	50% rice 50% OFC
Intermediate	80% rice 20% OFC	20% rice 80% OFC
Upland (well-drained)	20% OFC 60% upland rice 20% lowland rice	100% OFC

Notes: Lowland rice is ponded rice; upland rice refers to varieties that are dry-sown.
OFC = Other field crops

Source: ADB (1986).

[57] In 1990, work on Phase II expansion was discontinued because of doubts about the water supply.

Figure 10.2. Kirindi Oya Irrigation and Settlement Project.



quite low. The project is therefore designed to spread the water thinly over a large area to get the maximum benefit. Although Sri Lanka's irrigation settlement schemes have traditionally been rice-based systems, the diversified cropping pattern recommended by ADB for the Kirindi Oya Irrigation and Settlement Project (KOISP) is as in Table 10.1.

More recently, consultants to the Irrigation Department have proposed an alternative cropping pattern (Water Management Consultants 1987,16) based on two types of crops: lowland rice, and irrigated (but dry-foot) subsidiary field crops. The Project is in the initial stages of operation and to date (i.e., as of 1989) it has been operated to support rice crops only, to meet the immediate demands of the settlers. In the long run, it should shift to a "water use concept" to support intensification and diversification of agricultural production. The original concept of the project as one intended to support a diversified cropping pattern remains an untested assumption in terms of its practicality and sustainability. However, in this paper, we assume it to be an assumption worth testing.

Project Management Institutions

The Irrigation Department and Irrigation Management Division are the two institutions directly responsible for the operation and maintenance (O&M) of the system. The Irrigation Department is responsible for system O&M to the field-channel level. The water-related activities are directly under the charge of a Chief Resident Engineer. A Senior Irrigation Engineer for water management, working under the Chief Resident Engineer, is responsible for O&M of the new areas of the project, and for the preparation of irrigation schedules, including allocations between the new and old areas. Each of the main canals is assigned to an irrigation engineer for O&M; various technical assistants, work supervisors, and irrigation laborers complete the Irrigation Department staff. Other departments provide supporting services, such as agricultural extension and inputs, land administration, banks, and crop insurance.

At the field-channel level, farmers' groups organized by the Irrigation Management Division are supposed to be responsible for O&M. There are two Project Managers from the Irrigation Management Division, one each for the old and new areas. They are responsible for integrating and coordinating inputs of various departments into the agricultural production process, and for organizing farmers into groups and committees at field-channel, distributary, and project levels to obtain their cooperation. Neither the Project Managers nor the farmers' groups have any administrative or legal authority, and to date, both have been less effective than hoped.

A Project Coordinating Committee, consisting of project and district-level officials and chaired by the Government Agent (GA), has been constituted to take decisions regarding project activities, particularly those related to construction. A subcommittee of the Project Coordinating Committee was formed in mid-August 1988 based on an IIMI recommendation to discuss the agricultural programming for the project in detail. There are also two "Project Committees," for the old and new areas, organized by the Irrigation Management Division Project Managers. These committees include both

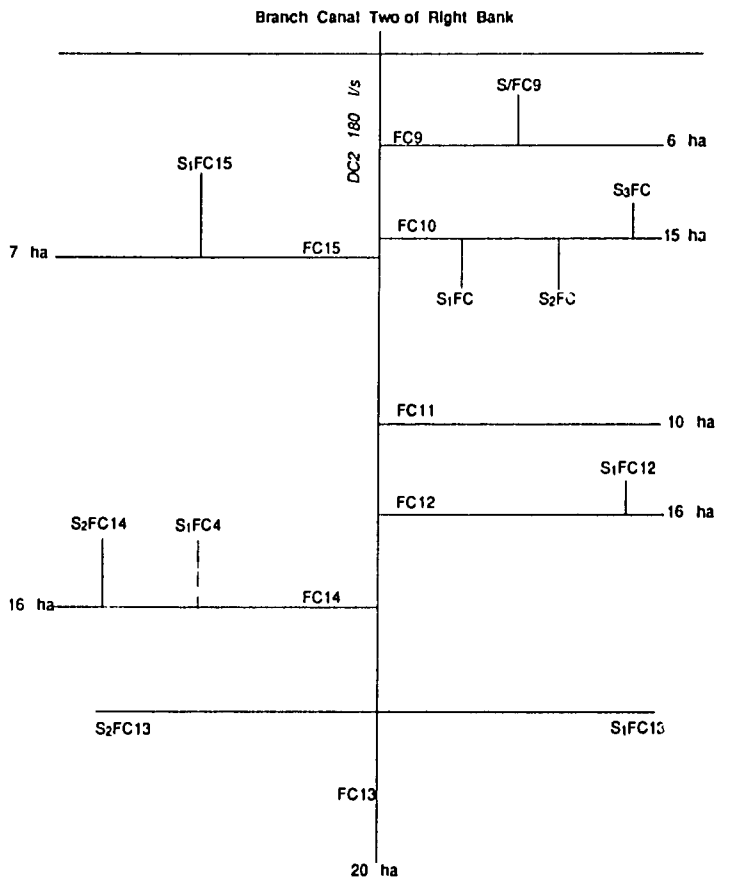
officials and farmer representatives, and are intended as policymaking bodies for planning and implementation of the agricultural calendar and for system O&M, but to date they have not been very effective. Finally, there is a subcommittee of the District Agricultural Committee, which has some authority in planning cultivation seasons.

The fragmentation and ineffectiveness of the management structure constitute a key factor underlying the unsatisfactory performance of the project.

WATER DELIVERY PERFORMANCF IN ONE SUBSYSTEM

The subsystem selected for this study consists of the distributary channel Number 2 (DC2) of branch canal 2 (BC2) on the right bank main canal (RBMC). It serves a command area of about 91 ha in Tract 5. Each of 91 farmers has an allotment of 1 ha. BC2, from which DC2 takes off, has a command area of 528 ha. While DC2 is the intensive sample study area, BC2 provides the basis for the extensive sample from the next higher-level subsystem (Figure 10.3).

Figure 10.3. Schematic Layout of DC2, Tract 5 of KOISP.



Data collected during the three agricultural seasons starting in February 1988 included hydro-meteorological data, seepage and percolation (S&P) data, discharge data at salient control points, design and operational data, socioeconomic data, and institutional data. However, the analysis presented here is based on the data collected during the yala (dry) 1989 season.

The 1989 yala season commenced with water issues on 15 March 1989, in line with the cultivation meeting decision in which farmers participated. This date was earlier than that recommended by the Irrigation Department, and was adopted at the farmer representatives' insistence. It allowed no time for channel maintenance, and water issues actually commenced before harvesting had been completed in some areas.

As is normal in Sri Lanka, one month was allowed for land preparation. The last date of water issue, originally fixed as 15 July, was later amended to 27 July, but the water issues for rice cultivation actually continued until about 10 August. The total rainfall during the season was about 220 mm, which was very close to the long-term average (250 mm) of the yala season. Most of the evapotranspiration (ET) values during the season were between 6-8 mm, except for a few days when the ET values were low (3 mm), corresponding to times when there were two or more days of continuous rainfall. The measured average value of S&P in the DC2 command area over the season varies from 4.7 mm/day to 10.8 mm/day. However, the S&P values adopted for the preparation of water delivery schedules are 3 mm/day for lowland soils (LHGs), and 6 mm/day for upland soils (RBEs) — i.e., much lower than the measured values.

A typical farmer takes about 4-5 weeks to complete land preparation, from the day he receives water on his allotment until sowing, as against the 3 weeks assumed in preparing the water schedule. The total time required for 100 percent completion of sowing in the study area from the first date of water issue is about 8 weeks as against the 5 weeks assumed in the water delivery schedule. The total quantity of water used by a typical farmer in DC2 for land preparation is about 880 mm/ha comprising about 400 mm/ha for land soaking and about 480 mm for other activities in land preparation, as against totals of 125 and 200 mm assumed for LHG and RBE soils, respectively. The peak daily deliveries of irrigation during the land preparation period are 3.41, 3.58 and 2.68 l/s per hectare at the heads of BC2, DC2 and DC5 canals, respectively. These values are slightly higher than the designed peak land preparation requirements at these levels of the system.

Predictability of Supply

The actual measured deliveries and the target deliveries at the heads of BC2, DC2 and DC5 are shown in Figures 10.4 to 10.6. The supply at the head of BC2 and other sample distributaries fluctuated significantly during the first week of land preparation. This fluctuation is mainly due to the opening and closing of distributaries and field channels taking off from the main canal, manipulations necessitated by the inability of the farmers to receive an early supply of water, and by the preseasonal maintenance

Figure 10.4. Measured deliveries and target deliveries at the head of BC2.

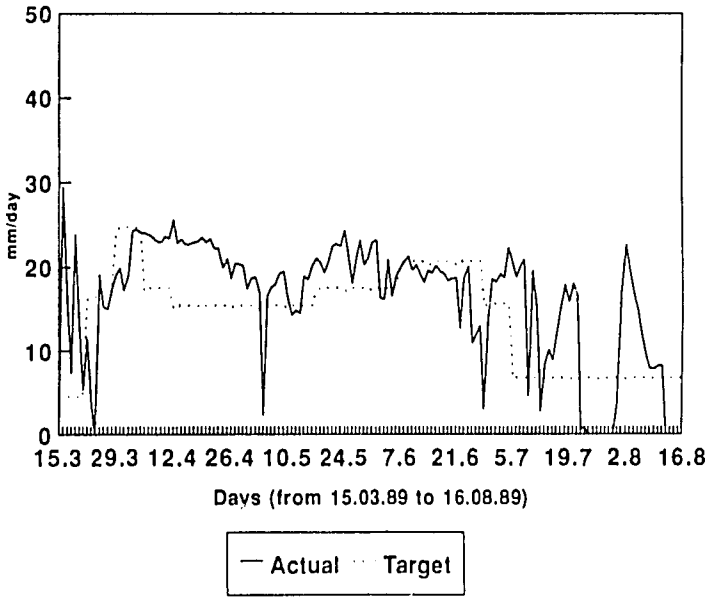


Figure 10.5. Measured deliveries and target deliveries at the head of DC2.

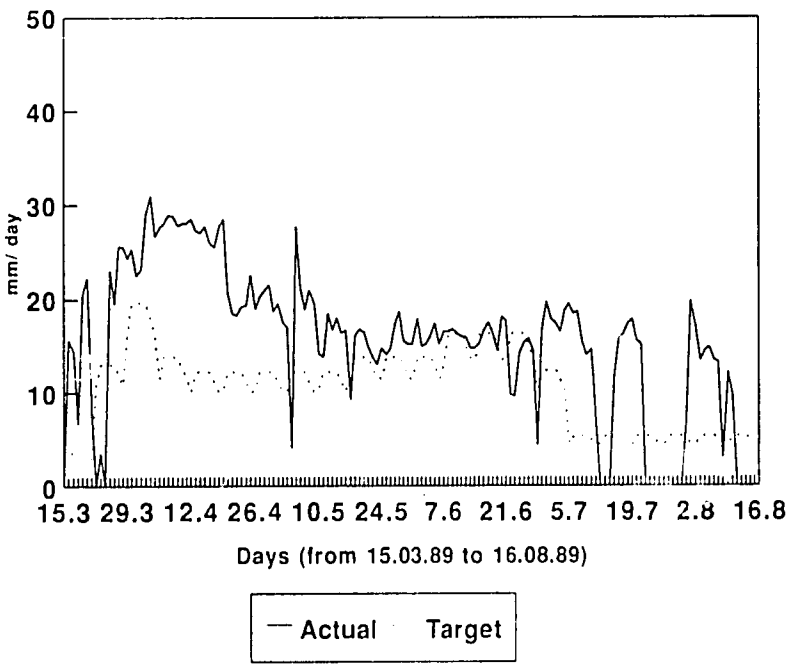


Figure 10.6. Measured deliveries and target deliveries at the head of DC5.

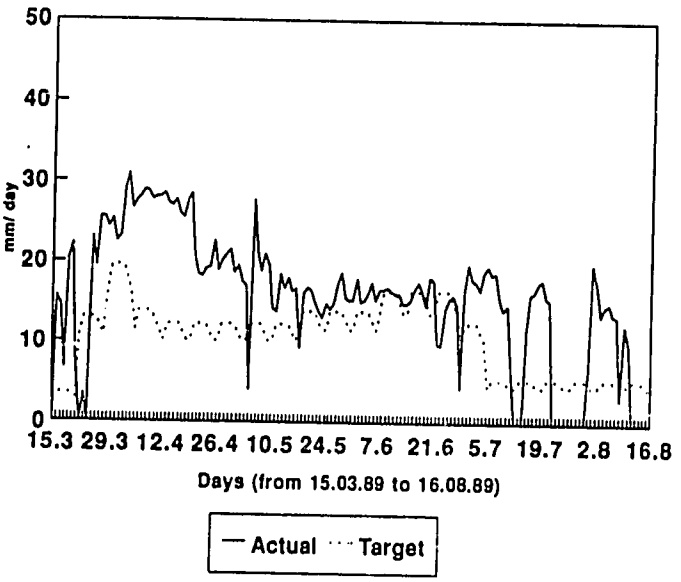


Figure 10.7. Measured discharges versus targets at the head of FC9 of DC2.

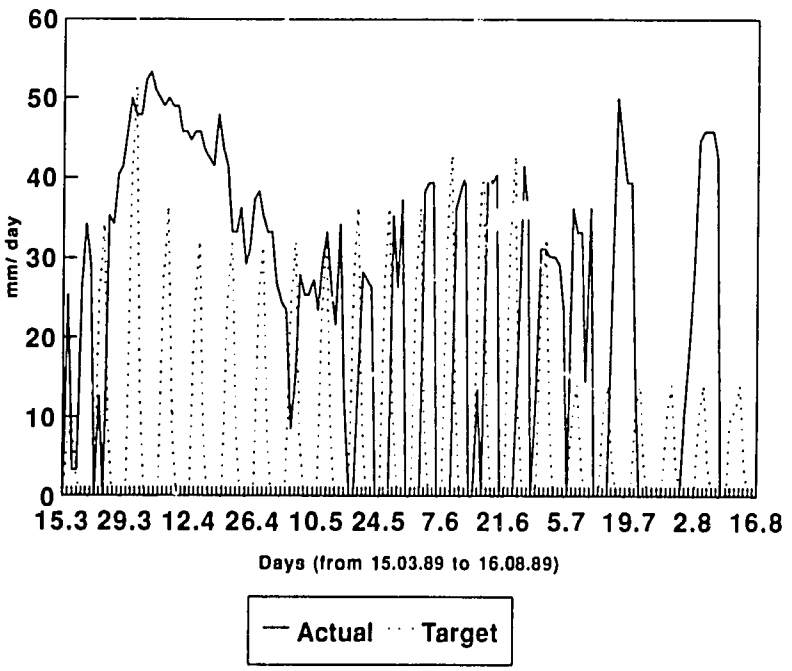


Figure 10.8. Measured discharge versus target at the head of FC10 of DC2.

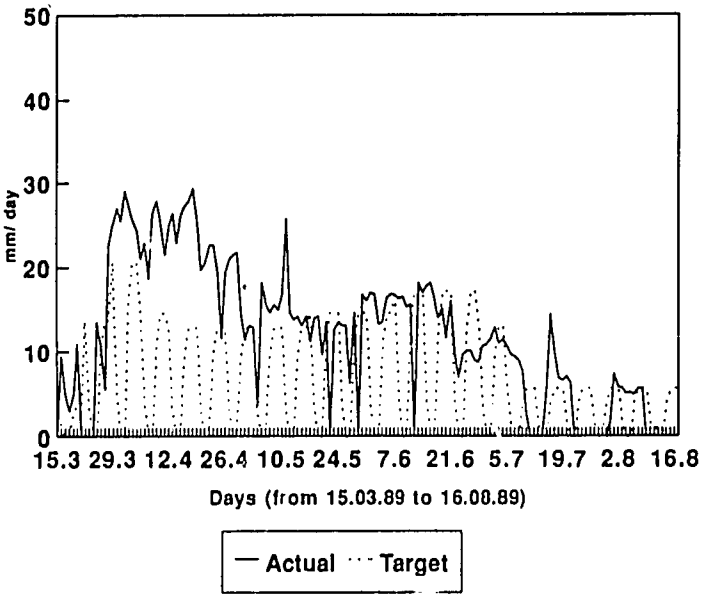
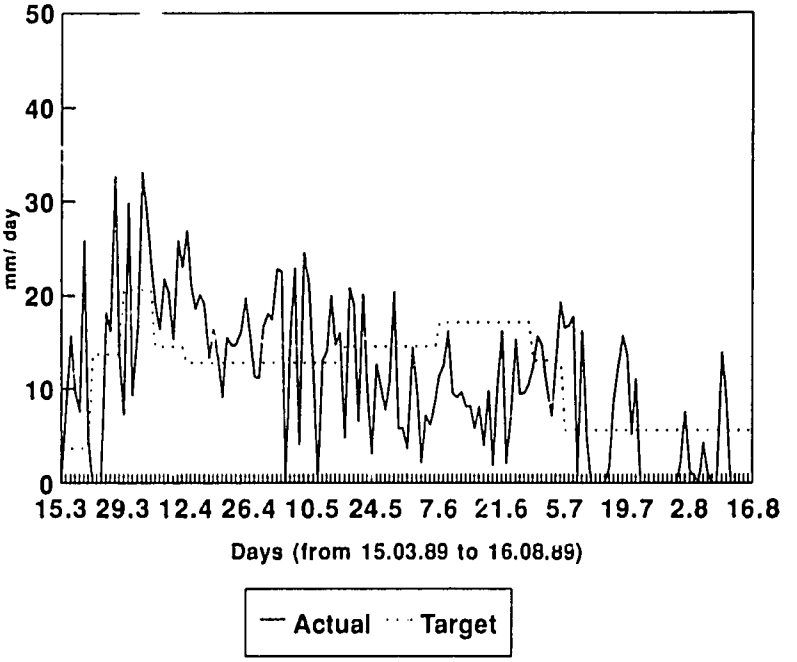


Figure 10.9. Measured discharge versus target at the head of FC13 of DC2.



activities carried out after the release of water for the yala season. It is also seen that from June onwards, the supply was gradually reduced, causing fluctuations at the head of BC2 and other distributaries. This gradual reduction was effected in order to conserve the dwindling storage in the reservoir, while the major fluctuations during this period were caused by the operation of the system to account for the rainfall in the service area. In the subsystem studied, although the supply deviated from the targeted release, the supplied discharges were by and large above the targeted values.

In Figures 10.7-10.9 the measured discharges are plotted against the targets at the heads of FC9, FC10 and FC13 of DC2, representing head, middle, and tail field channels. The figures indicate that the rotation within field channels was introduced only two months after the date of water release, because of the slow rates of land preparation achieved by the farmers. The water supply against the target was predictable except in FC13, the tail-most field channel of DC2, where more than one-third of the allotments (about 7 ha) did not depend on the irrigation supply, as they have access to drainage water for cultivation.

Adequacy of Supply

The adequacy of a given water delivery is a measure of the reliability of supply and, in turn, a measure of the quality of system operation. The adequacy can be evaluated in terms of Relative Water Supply (RWS), which for our analysis is defined as follows (all units in mm):

For land preparation period:

$$RWS = (IW + Re)/(E + S\&P + \text{land soaking and ponded water})$$

For crop growth period:

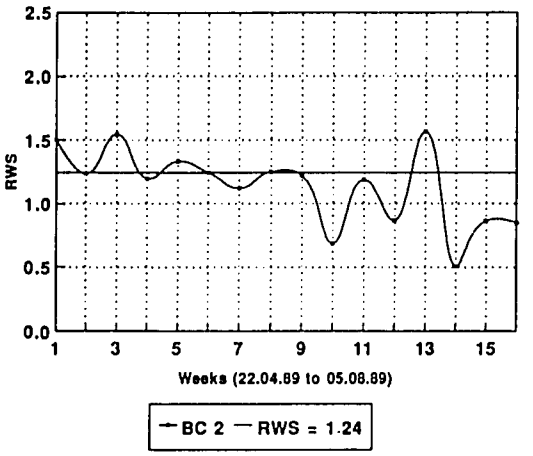
$$RWS = (IW + Re) / (ET + S\&P)$$

where
- IW = Irrigation water delivery
- Re = Effective rainfall (assumed as total rainfall for yala)
- ET = Evapotranspiration
- S&P = Seepage and percolation
- E = Evaporation

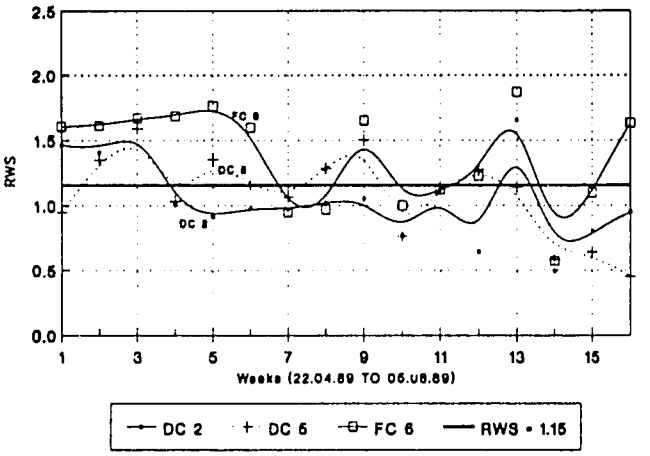
The weekly RWS values at the heads of BC2, FC6 (head), DC2 and DC5 are presented in Figure 10.10, A-D. Similar computations were carried out for the field channels of DC2, and typical curves are presented in the same series of figures. A RWS = 1 at the field means that the supply matches the requirement exactly and is called the "critical RWS" value. If the irrigation water supply is measured anywhere other than in the field, such as a field channel or distributary turnout gate, then the conveyance losses in the channel need to be accounted for in computing RWS values at the field. This would then make the critical RWS values higher than 1. For the purpose of our analysis, the conveyance efficiency in a typical field channel, distributary channel, or branch canal was assumed to be 93 percent, as adopted in the water delivery schedules prepared by the Irrigation Department. This results in "critical RWS" values of 1.07, 1.15 and 1.24

Figure 10.10. The weekly RWS values at the heads of BC2, FC6 (head), DC2, and DC5 and field channels of DC2.

(A)



(B)



(C)

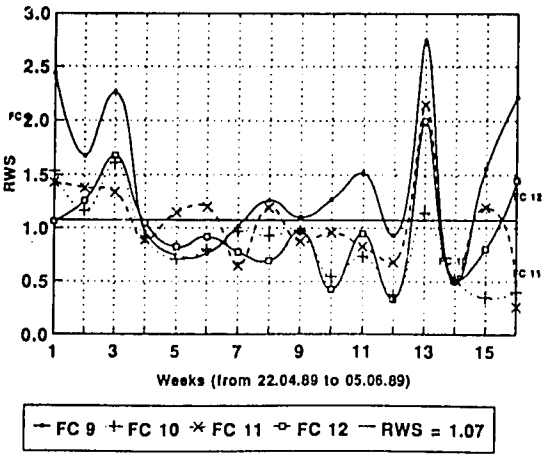
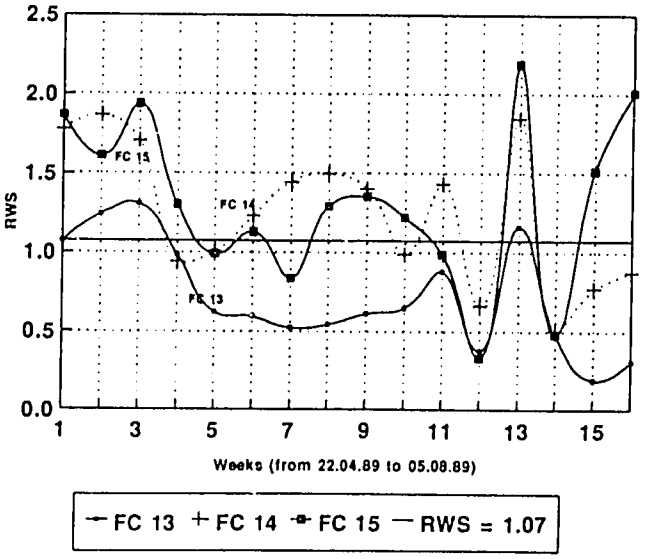


Figure 10.10 (Continued)

(D)



at the head of a typical field channel, distributary channel, and branch canal, respectively.

A comparison of the weekly RWS values in the sample subsystem with the critical RWS values indicates that the actual RWS was above the critical RWS level for most of the time, both along the branch canal and at the heads of distributaries. At the same time, a general trend of gradually declining RWS values over time can be observed, possibly due to the deliberate reduction of supply by the Irrigation Department in view of the gradually declining storage in the reservoir. Similarly, the distribution of computed RWS values at the heads of field channels under DC2 indicates high RWS values throughout the growing season, except for those field channels that receive drainage water (FC10, 12 and 13).

The low values of RWS (0.5 to 0.80) prevailing at the heads of field channels during the latter part of the season imply "undersupply." However, a more sensible comparison of the actual RWS values with the distribution of rainfall over the season, as well as the actual deliveries into the RB main canal and to the other canals in the subsystem, brings out the fact that the Irrigation Department had made a serious effort to economize on water during the rainy periods by either completely withdrawing or reducing the irrigation supply during and after the rains.

Equity of Water Supply

Table 10.2 indicates the mean RWS, maximum and minimum RWS, and the water delivery performance (WDP) parameters as defined by Lenton (1983) assuming equal

weights for all periods of the growing season. It is seen that if actual rainfall is taken into account, WDP for all the canals (except FC10, FC12 and FC13) is near or above 1.0, indicating adequate supply. The field channels where WDP is very low benefited from the drainage water in DC2 for part of their command areas.

Table 10.2. Relative water supply (RWS) and water delivery performance (WDP) in yala 1989, RB Tract 5-BC 2 subsystem.

Canal	Maximum RWS	Mean RWS	Minimum RWS	WDP
BC 2	1.57	1 14	0.50	1.12
FC 6	1.87	1.38	0.57	1.36
DC 2	1.65	1.06	0.49	1.08
DC 5	1.59	1.08	0.45	1.08
FC 9	2.74	1.43	0.48	1.36
FC 10	1.62	0.85	0.35	0.81
FC 15	2.19	1.32	0.33	1.27
FC 11	2.15	1.04	0.26	1.00
FC 12	2.00	0.98	0.33	0.94
FC 14	1.87	1.25	0.50	1.23
FC 13	1.31	0.72	0.19	0.74

The distribution of mean RWS values along the branch canal and along DC2 is presented in Figures 10.11 and 10.12. The mean RWS, both in the branch canal and in the sample canals along BC2 is higher than 1.0. Along the branch canal, the supply is not equitable, varying between 1.39 at the head to 1.05 at the middle and tail. Though the head-end (FC6) received more supply, possibly due to its position along the branch canal, the agency has succeeded in maintaining a fairly equitable supply between the middle and tail reaches of the subsystem studied. As far as equity among the field channels within DC2 is concerned, it is observed that the mean RWS of the head end (FC9) and tail end (FC13) are 1.41 and 0.75, respectively. However, contrary to the common perception, mean RWS does not decline gradually from head to tail in proportion to the length of DC2. Some middle and tail field channels attained high mean RWS values (e.g., FC15 = 1.30; FC14 = 1.25) very close to the mean RWS value at the head-end field channel. Only two field channels (FC10 and 13) out of the seven received less than a mean RWS of 1, but both of these benefited from the drainage water from the upper areas.

An inherent weakness of the RWS methodology in assessing the adequacy of supply is that it fails to account for the use of drainage water or for residual water left in the fields due to rain or overirrigation that can be used to supplement the water requirements in the subsequent weeks. The concept of cumulative RWS instead of RWS accounts for the residual water and gives a better representation of available water at the field level. A plot of cumulative RWS as a function of time is shown in Figure 10.13, A-D for BC2, DC2, DC5, FC6 and for field channels along DC2. One can observe

Figure 10.11. The distribution of mean RWS values along the branch canal.

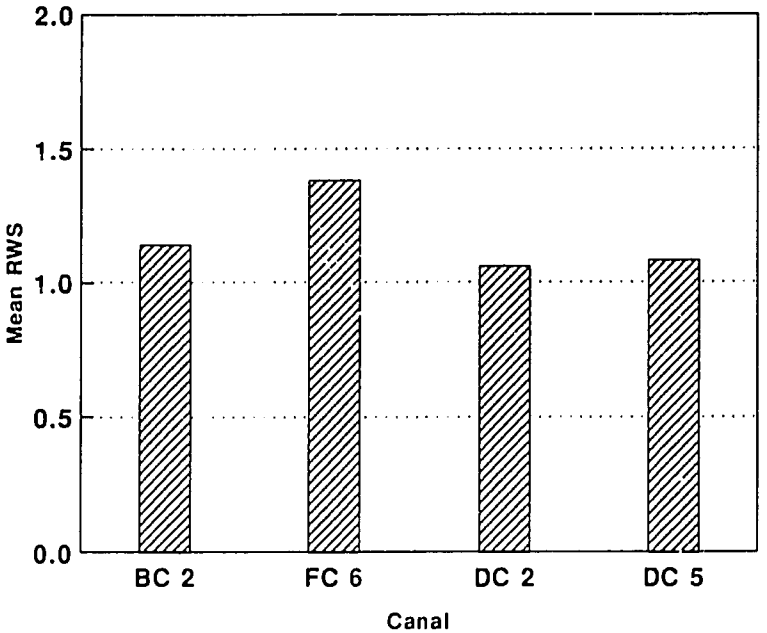
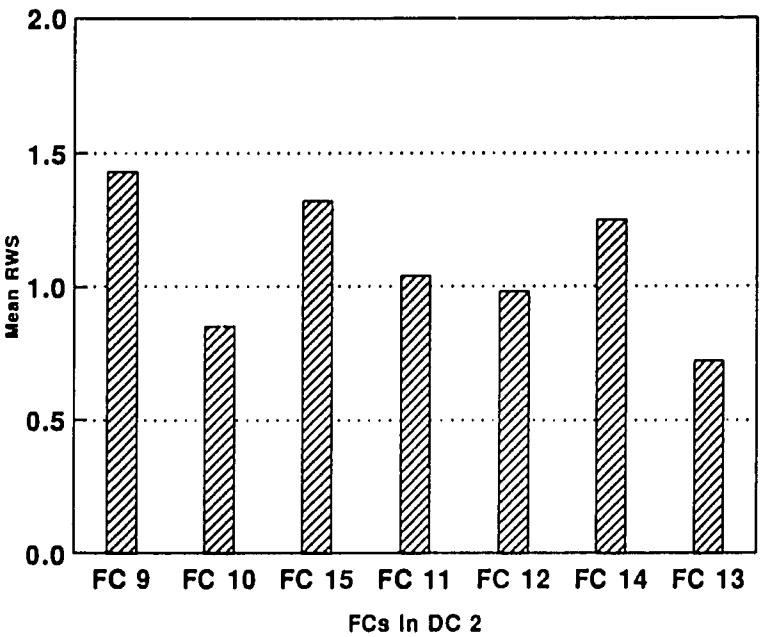


Figure 10.12. The distribution of mean RWS values along DC2.

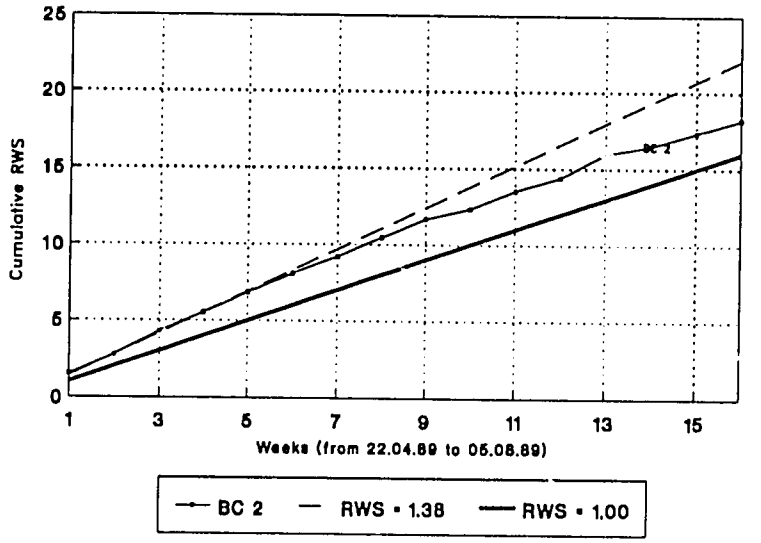


from these plots that the adequacy of water along BC2 as well as along DC2 is clear and was always equal to or greater than its requirement, except in FC10 and FC13 which have been receiving drainage water.

Although equity among the field channels of the sample subsystem was found to be within acceptable limits, there was a wide variation of water level in the rice fields in different areas, as well as within the same area (maximum 18 cm to minimum –50cm from the bed level).

Figure 10.13. Cumulative RWS as a function of time for BC2, DC2, DC5, and FC6 and for field channels along DC2.

(A)



(B)

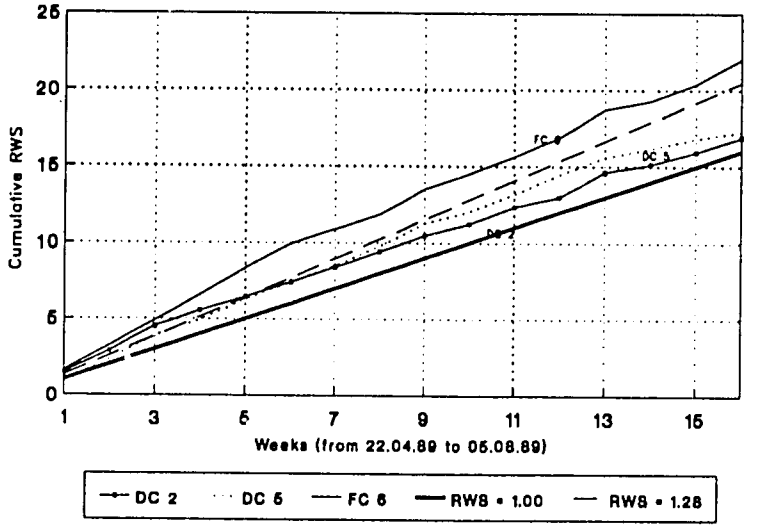
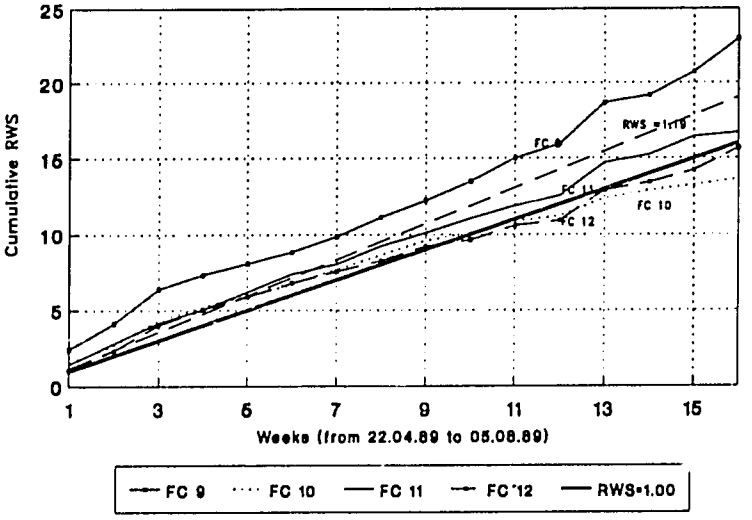
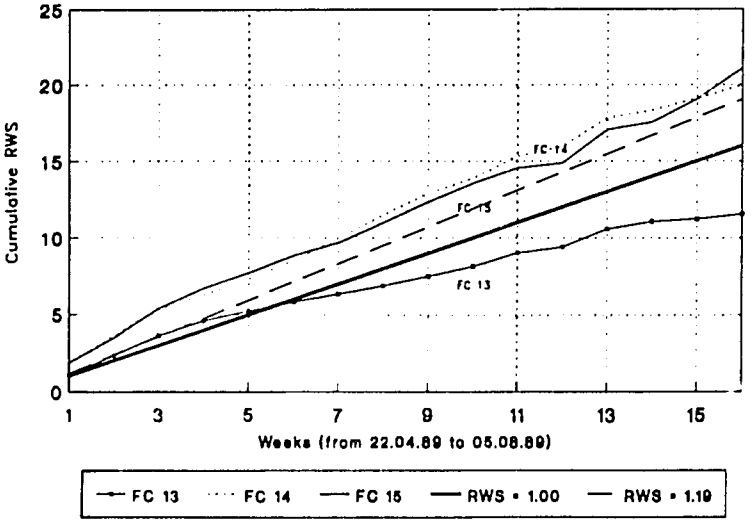


Figure 10.13 (Continued)

(C)



(D)



The wide variation within and between the turnout areas is an indication of ineffective water distribution by the farmers in the field-channel turnout areas. One of the operational assumptions of the design of turnout areas is that the farmers in any given field channel form a cohesive group to share the entire flow in the field channel between two farmers at a time during the rotation interval. While it is true that the Irrigation Department was also unable to adhere to a strict implementation of rotation among field channels, it was also observed that farmers practiced no systematic sharing of the water delivered. In fact, this was the first season in which we observed a pattern of farmer interventions such as manipulating field channel and distributary gates and cutting channel bunds. This, and the high degree of water level fluctuation in rice fields, pinpoint the importance of improved management at the farm level to avoid crop stress.

The following are the important findings of this aspect of the research:

- There exists a considerable difference between the design and operational assumptions and the realities especially during the land preparation phase.

- Although the general pattern of water delivery during the season reflected a trend of fluctuating deliveries at the beginning of the season with a gradual reduction towards the end of the season, the efforts made by the Irrigation Department to match the total supply (irrigation water plus rainfall) to the actual field water requirements made the supply adequate.

- The water used per hectare at branch-canal and distributary-turnout levels during yala was more than adequate, as shown in Table 10.3. This indicates a high potential for water savings in future.

- The water delivery performance during yala 1989 emphasized the necessity of strengthening the communication among farmers, farmer representatives, and agency officials. While there has been considerable improvement in managing the main system during this season by the agency officials (compare IIMI 1988b and 1989a to IIMI 1989b), the management below the turnout needs substantial improvement through effective farmers'organizations.

Table 10.3. Water use at selected turnout gates.

Canal	Position	Land preparation mm	Crop growth mm	Total mm
BC 2	-	723	1,974	2,697
FC 6	Head	885	2,405	3,290
DC 2	Middle	822	1,790	2,612
DC 5	Tail	541	1,662	2,203

DESIGN, CONSTRUCTION, AND MAINTENANCE CONSTRAINTS ON PERFORMANCE

Design

The design influences the performance of the project in two ways — through the formal set of technical procedures and assumptions adopted for the design of irrigation canals and appurtenant structures, and through the typical operational schedules for the distribution of water.

The size of the turnout area served by any individual field channel is designed on the basis of 8 ha for 100 percent Reddish Brown Earth (RBE) soils and 16 ha for 100 percent Low Humic Gley (LHG) soils. Thus the actual size of any field-channel turnout area is, in principle, determined by the proportion of different soils served by that field channel. However, a random verification of some field-channel turnout areas indicates that the actual proportion of RBE soils has been underestimated in some instances and that turnout areas are larger than expected. This situation can impose capacity constraints on delivery of peak daily irrigation requirements (3.50 l/s per ha for RBE and 1.80 l/s per ha for LHG) with a standard field-channel capacity of 30 l/s.

The design of the irrigation system has underestimated the seepage and percolation rates through the soils. This too can impose capacity constraints in some canals where the exact design section exists without any buffer free-board.

The cross regulators provided along the main canal are intended to insure the driving head required for the release of design discharges to the offtakes located upstream. The trial and error manual procedures adopted for the manipulation of cross regulator gates in order to maintain upstream head and simultaneously to release the required discharge for the downstream command areas cause water-level fluctuations along the main canal.

The designers of the Kirindi Oya irrigation system focused on the management of rice irrigation, since the entire system is actually designed and operated for rice. Little attention has been paid to designing and laying out the system for a mixed cultivation of rice and nonrice crops — even though it was known that the system must support a mixed cropping pattern.

The basic operational design for the water delivery schedules anticipates scheduled rotational irrigation for rice, with the rotation to occur among the field channels and the sharing of water to occur between the farmers. Our research indicated that rotations among the field channels were not implemented systematically and the sharing of water below the field-channel turnouts was taking place in unsystematic and informal ways. This pattern of operation leads to undersupply or oversupply, and eventually to wastage of water.

The preparation of the water delivery schedules for each season begins with information about the intended dates of first irrigation issue and land preparation activities. The period usually allowed for land preparation is one month, but various socioeconomic constraints stretch the land preparation period beyond one month.

The delay in land preparation causes the operation to be carried out in an ad hoc manner during the land preparation period.

The underestimation of seepage and percolation rates and canal conveyance efficiencies in the irrigation schedules can lead to undersupply in some areas (IIMI 1988b).

Construction

The quality of construction also has an impact on water delivery performance in a number of ways.

A set of "as-built" drawings for the irrigation canals should be prepared immediately after construction in order to ascertain the design levels of the canals and other key structures. In Kirindi Oya the as-built drawings are not yet available, and the deviations from the designs during construction are not systematically recorded. This makes it difficult for the operating agency to recognize construction defects, and the true capacities of the canals and control structures. The operation takes place with an implicit assumption that the construction is perfect, which is far from true. For example, our preliminary investigation of BC2 and sample distributaries indicates a mismatch between the design and existing canal-bed levels.

The quality of construction which is a key issue in the long-term performance of the system appears to be average in Kirindi Oya, by Sri Lankan standards. However, work of inferior quality and inadequate foundation work can also be observed. Some canal structures are already undermined or partially collapsed.

The construction of drainage canals received low priority in the construction process. These were done last, and this delay caused the development of salinity and waterlogging in some lower patches of the command of canals. This state of affairs could have been avoided, to a certain extent, if the construction of drainage canals had taken precedence over the construction of irrigation canals, or if the drainage canals had been completed before the first cultivation season.

Maintenance

Once the system is constructed, the quality of the maintenance will determine the long-term capability of the water delivery system to perform at expected levels. Lack of as-built drawings prevents the identification of the actual degree of silting in the canals. This is a major drawback in the overall performance of the system.

The decisions on when to commence the water issue for a season, taken at cultivation meetings, sometimes leave no adequate time for preseasonal maintenance of the system. This leads to operational difficulties and eventually to closing of some canals for desilting after the season has begun. The farmers show very little interest in cleaning and maintaining the field canals. They are not properly organized or motivated to attend to maintenance work.

The main constraint is believed to stem from insufficient funds allocated for maintenance, at least for the routine weeding and desilting of canals before the commencement of a season. The lack of a systematic and well-established procedure for prioritizing and conducting maintenance activities further inhibits performance.

LONG-TERM RESOURCE CONSTRAINTS ON WATER DELIVERY PERFORMANCE

A major objective of the Kirindi Oya project is to make efficient use of scarce water, land, and human and financial resources to maximize farmers' production and income. This is a water-deficit project with very high variability of reservoir inflows. The flow pattern of the Kirindi Oya and its tributaries shows minimum/maximum ratios of 1/6 for annual, and even 1/70 for monthly flow volumes. The long-term average annual inflow into Lunuganwehera Reservoir is estimated at 319 MCM with roughly 114 MCM in the yala season (March-August) and 205 MCM in the maha season (October-February). The old Ellagala system contributes a total of 102 MCM of average annual inflow to its five tanks from its own catchment, giving an overall average availability of 421 MCM in the system. A comparison of recent discharge measurements with the original series of inflow data shows that the recently measured actual inflows are 30 to 40 percent less than originally estimated. Moreover, the reservoir water would be just sufficient to raise one rice crop in the contemplated service area of 12,900 ha. Therefore, use of this water to raise two crops in the area needs very careful water planning, and crops requiring much water, like rice, must be minimized.

The soils within the project service area fall into three main types: reddish brown earths which are moderately coarse and highly permeable, suited for the production of upland crops; low humic gley (LHG) soils which are slightly finer, less permeable, and poorly drained; and alluvial soils rich in clay and finer sediments of fertile river-transported soils. Both LHGs and alluvial soils are suitable for rice cultivation because of their physical properties and physiographic position in the landscape. However, raising rice in the upland area may create waterlogging and salinity in the lowland areas at times of water abundance.

Most of the settlement farmers come from the lower socioeconomic strata of the country, are young with no grownup children to help them in the farming activities, and have to depend heavily upon hired laborers and farm power for agricultural operation. Some settlers have little or no agricultural experience. Hired labor is very costly in the region. This has serious implications for the cultivation of nonrice crops which require more labor. In the study area, 70 percent of the farmers obtained loans from either institutional or informal sources, or both. The interest rate for informal loans is very high (as high as 120 percent per year). Because of the drought and crop failure in the first season (1986/87 maha), about 40 percent of the sample farmers have defaulted on bank loans and are no longer creditworthy. A serious constraint for any innovative development in this project appears to be the poverty of the settlers.

Limited financial resources have had a great impact on the potential performance of the system: cost overruns have led to delays in implementation, and a "least cost"

approach is taken in providing all infrastructure and basic services. This underlies some construction quality as well as design problems, inadequate support to settlers to assist them in making the transition to being residential irrigated farmers, and the continuing lack of many basic facilities.

Keeping in mind the insufficient and uneven water supply, increased pressure on the available land for agricultural production, and the need for settling as large a number of farmers as possible at the lowest possible cost, the planners of the project and the water management consultants have recommended a mixed cropping pattern to complement and alternate with rice cultivation. The draft water management strategy plan submitted in May 1987 was worked out for a cropping pattern based essentially on two crops: lowland rice and irrigated subsidiary field crops. These field crops are a mixture of 50 percent 3.5-month-age-group upland crops, and 50 percent 4.5-month-age-group upland crops, both already grown locally to some extent. This cropping pattern would allow irrigation of only the old area plus Phase I of the new area with an acceptable cropping intensity of 175 percent. The intensity, however, drops to an unacceptable 130 percent if the whole Kirindi Oya Project (phases I and II) is included. Because of the low cropping intensity, it was agreed during a joint ADB-Kreditanstalt fur Wiederaufbau review mission in June 1987 that other cropping and water allocation approaches should be investigated. The water management consultants have now recommended a cropping pattern similar to the one given in Table 10.1, based on their simulation studies (Water Management Consultants 1987).

While as of 1989 no decision had yet been taken by the government or the project authorities with regard to the cropping pattern to be implemented, farmers have been cultivating rice throughout the command (upland and lowland soils) in both the maha and yala seasons. Before yala 1989 began, the Irrigation Management Division officials and others attempted to convince farmer leaders to grow other crops, but they were reluctant, for many very good reasons. The Irrigation Department indicated that there was sufficient water to start a rice crop in Tracts 2 and 5 of the right bank, undermining any further effort to change the cropping pattern. The Department did not, however, inform the farmers about the impact of the decision on the possibility of irrigating larger areas, or on the starting date of the following maha. In any case, farmers face various technical, management, and institutional constraints on growing nonrice crops, which are yet to be dealt with by the agencies concerned both at the national and project levels.

Raising rice in both seasons has resulted in a number of problems, both during the yala 1989 and maha 1989/90 (in progress as this paper was written):

- The decision to raise rice during yala 1989 with inadequate storage at the beginning of the season made the Irrigation Department very cautious about water releases from the reservoir, resulting in unreliable water supply especially during the initial stages of land preparation and also during the final stages of crop growth. Since the Department was severely criticized by settlers for its handling of the drought in maha 1986/87, which had led to a total crop failure (see Merrey and Somaratne 1989), its conservatism is understandable. Its objective of conserving the scarce reservoir resource whilst making maximum

use of the rainfall and drainage water has resulted in uneven and, at times, inadequate supplies to certain sections of the service area. Better coordination and communication between the farmers, farmer representatives, and agency officials could have improved this situation considerably.

- An even more serious problem for the long-term performance of the system is that raising rice during yala 1989 has left very little water in the reservoir to start the maha 1989/90 in time and to the full extent. The old areas are receiving issues and will have a maha season; and some new area tracts may receive late issues depending on the inflow. This continues a pattern observed since the first season of the project (yala 1986): at any given time, only a few tracts can have a season, but the whole system has never had a simultaneous season. There is a continuous pattern of low intensity land use. This will lead to underdevelopment of the new area, causing social and political dissatisfaction, and could jeopardize the economic viability of the project.

- Once the farmers have become used to growing rice during both the yala and maha seasons it may be difficult to induce them to switch over to other crops at a later date, unless such a change is going to improve the profitability to the farmers substantially. This has been the experience in many Asian countries. By the time the larger system is ready for farmers to shift, they may have neither the inclination nor the resources to do so.

The above arguments and discussion underline the need for two things: a clear and early policy decision with regard to the cropping pattern in different zones of the project area (old system, RB and LB of the new system) and its implementation from the very beginning of the project; and effective infrastructural development for implementing insurance cover for other field crops, bank credit at low interest rates, marketing, and post-harvesting storage facilities for diversification into other field crops.

SOME OTHER ISSUES AFFECTING SYSTEM PERFORMANCE

Priorities in Irrigation Settlement Projects

Although Kirindi Oya is an *irrigation* settlement project, the government gave first priority to settlement. This is due mainly to political pressure — the settlement of beneficiaries was done well in advance of physical construction. Construction of irrigation facilities was given the next priority, but unfortunately, there were significant delays due to improper planning and cost overruns in creating the necessary irrigation infrastructural facilities. This led to a large time gap between settlement and the provision of irrigation services. Having settled the poor farmers and established the necessary infrastructural facilities, the government has not provided the necessary

support for irrigation management, including institutional aspects. Coupled with social unrest and droughts, this has had a negative impact on system performance.

Water Allocation Conflicts between Old and New Areas

Many settlement projects in old and new areas have had problems of sharing water among themselves. The old settlers who gain considerable benefit after construction of the project, by way of stabilized irrigated agriculture due to a more reliable water supply and increased intensity of irrigation, nevertheless look upon the new settlers as intruders in their domain of influence. The farmers in the old area generally use more than their allotted share of water, complicating and distorting the allocation of water to different areas.

This can be illustrated with data from the Kirindi Oya project, where the Ellegala old system used to irrigate approximately 130 percent of its service area before the construction of Lunuganwehera Reservoir. In the project proposal, an irrigation intensity of 160 percent with some other field crops for the old system was assumed (without consulting the farmers); but the farmers in the old system now irrigate two rice crops (nearly 200 percent intensity) thereby depriving the newly developed areas of water. The concept of prior riparian right is clearly prevalent in the farmers' minds. This problem must be examined, and a clear policy decision has to be arrived at and enforced; otherwise, one ends up with a system in which a large deficit of water supply occurs in much of the newly developed area.

Another characteristic of reservoir projects in particular is a tendency to switch from the designed cropping pattern to water-loving crops such as rice. This reduces the available water supply to the tail-end region. All these factors suggest the need for better interaction with the public, through such means as a public-hearing system, from an early stage.

Mismatch between Assumed Design and Actual Water Requirement

Many new settlement schemes consume more water than do stabilized irrigation systems, especially when rice is the crop cultivated. Experiences from the Kirindi Oya and Inginimitiya projects indicate that the excess consumption may be as much as 100 percent above the requirements of a stabilized tract (Franks and Harding 1987). There are many reasons for this. First, the virgin soil, when it is irrigated with ponded water for rice cultivation, has high S&P values. In such soils, no clay pan has formed. The horizontal seepage through field bunds is also very high.

Second, settlers do not have adequate resources in terms of equipment (tractors, bullocks, laborers, etc.) and funds to enable them to adhere to strict water scheduling, especially during the land preparation period. For example, farmers in the Kirindi Oya project took two months during the yala 1989 to complete the land preparation as

against one month of stipulated time, and used roughly 880 mm of water per hectare, which by any standard is very high. Therefore, in new settlement projects, excess use of water is bound to occur during the initial stages of project development and this aspect needs to be considered while water budgeting for the project.

Behavioral Pattern of Settlement Farmers

The settlement farmers are a group of people coming from different walks of life with diverse social habits and cultural patterns. Many have had no experience in irrigated agriculture; in interviews a few have even stated they have no wish to be farmers. Though, by law, the settlers should not possess any other land or business to be eligible for receiving land, some of them own land or are engaged in business in their original villages. They generally commute between the settlement hamlet and their own village where their families and relatives live. The frequent absence of many farmers from the settlement hamlets hampers efforts to organize farmers for irrigation management. In the Kirindi Oya project, about 30 percent of the farmers have apparently already leased out their allotments. Only the poorest of the poor stay in the settlement hamlets, and they posses neither the incentives nor the resources to carry out efficient farming operations.

Many settlers were brought to the project area long before the supply of water, in the hope that these farmers would work on their allotments and prepare them for irrigation, but many have had to wait up to three years for the first water supply. During this intervening period, they have had to depend on a government food subsidy. Many of them had spent whatever savings they had brought with them. Therefore, at the time of starting the irrigation, they had to borrow money either through banks or from private sources. Under these conditions, even if there is one crop failure (as in fact there was), many farmers cannot overcome the crop loss and consequent financial losses.

CONCLUSION

We are at too early a stage in our analysis and thinking to come to firm conclusions, but a few observations can be made. Franks (1989) and Franks and Harding (1987) have focused attention on the special nature of the problems in "commissioning" new irrigation systems, based on work in another new irrigation settlement scheme in Sri Lanka. They note that in the initial stages there is a tendency to use water far in excess of design assumptions. If this is catered to, it often leads to head enders becoming accustomed to receiving water in excess of crop requirements, a difficult habit to change later. System managers are not sensitized to the special nature of the commissioning period, and are not trained to take special precautions. Franks and Harding (1987) suggest, for example, that in the first seasons only 50 percent of each rice allotment should receive water. Franks (1989) also refers to Stanbury's (1989)

work in Kirindi Oya on the lack of "commissioning" to enable settlers' institutions to develop and work effectively.

Kirindi Oya presents a special problem not faced in most other Sri Lankan irrigation settlement schemes. Kirindi Oya is a comparatively severely water-short system, which has been justified economically from the beginning on the assumption that farmers would grow a lot of nonrice crops. In the Appraisal Report (ADB 1986), a 200 percent cropping intensity is stated as the objective, with a mixture of rice and nonrice crops as given in Table 10.1. More recently, the water management consultants have proposed as the "most feasible" scenario one that mixes rice and other crops on lowland areas, and irrigated and rain-fed crops on upland areas (Water Management Consultants 1987: Volume 1). This is based on computer simulation modeling of the likely water availability in the project area.

With hindsight, as noted above, it can be seen that serious errors were made in the planning and design stage. Although mixed cropping was a stated objective, the designers assumed that the normal design parameters used for rice-based systems could also cater to the demands of nonrice crops. While this assumption is not invalid, the present design permits rice cultivation on well-drained soils in a system whose total water supply is inadequate to support this crop. No operational plan was developed, let alone validated, at the design stage for the support of nonrice crops. The situation is compounded by the serious underestimation of total water availability. The rice-based design and operations to date are totally inappropriate, given the water and soil conditions in Kirindi Oya. Since a complete redesign and reconstruction of the system are not feasible now or in the near future, the government must focus on institutional and management inputs that we believe could improve the performance significantly, even given the present design.

To date, the Kirindi Oya system continues to be operated as a rice-based system, in which only small patches of nonrice crops are grown with special assistance from the Department of Agriculture. We suggest there are two reasons for this pattern. First, there is a continuing "rice bias" or "rice-based thinking" underlying the management of the system. Farmers and officials share a fundamental and deep-rooted bias towards rice. There are strong cultural reasons for this, but this bias probably has so far prevented farmers and managers from seeing alternative scenarios (such as the one proposed by the water management consultants) as practical, or at least worth a serious test.

A far more significant factor lies in the project management structure. The water management consultants were consultants to the Irrigation Department. But this Department does not have responsibility for achieving the overall project objectives, or for implementing a long-term agricultural production plan. Its job is to deliver water, within the constraints imposed by water availability, finances, the physical condition of the system, etc. It responds to farmers' demands to the extent possible, but since both farmers and the Department are accustomed to dealing with irrigated rice crops, that is what they do. Other agencies have their own specified technical functions, but no agency is responsible for achieving the long-term objectives of the project.

There is therefore a de facto policy of catering to short-term objectives, i.e., providing water for rice in a few tracts, on an ad hoc tract-by-tract rotating basis, depending on

the water in the reservoir at any given time, but with the old area always getting sufficient water for growing rice two seasons per year. This satisfies farmers' short-term interests, as they wish to grow rice, and it is easy since the agencies, whether the Irrigation Department or the Department of Agriculture or others, know how to support rice production. New area farmers have not yet organized against the old area farmers, but the latter are organized to demand priority. Further, the various farmers' objectives may be quite at variance with the objectives of the management agencies.

The result is that the system management is unable to get the system as a whole onto a seasonal rotation, i.e., maha-yala-maha. As the reservoir was emptied to support yala 1989, only the old areas and perhaps one or two new area tracts will have a maha crop — a late maha rice crop — in 1989/90. The same pattern is repeated in yala, with some tracts even straddling the seasons (late maha or early yala) and growing rice. The precedence of short-term objectives prevents the achievement of longer-term objectives, and reduces the likelihood of achieving them as people get used to a certain pattern.

The research conducted in the BC2 subsystem indicates the potential for improving the water delivery performance with the active involvement of the system managers, including farmers, in actual operations. Recent signs of improvement (see IIMI 1989b and 1990) stemmed from organizational changes within the Irrigation Department. This may be a starting point for further improvement. However, interagency cooperation must be strengthened and a system for reconciling the objectives of various groups of farmers and agencies is required if the long-term objectives of the project are to be achieved.[58]

Since a major cause of the problem is institutional and managerial, the solution would also appear to lie in this realm. It is necessary to establish an overall project management system, which has the long-term objective of making the best use of the limited water to maximize farmers' incomes, and which has the authority to insure that other departments contribute their efforts to achieving this objective. Performance of the overall management would be assessed on the basis of its achievement of the longer-term objectives; assessment of the performance of other departments would be based on their contributions to their achievement. Institutions to facilitate consultation with, and the involvement of, legitimate farmer representatives would be a requirement, as would political support from above.

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[58] Since mid-1989 the government has taken important steps that at least begin to address these issues; the management changes initiated after an early draft of IIMI's final report are documented in the final report (IIMI 1990), and future reports will document the impact of these innovations.

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CHAPTER 11

Performance of Secondary Canals in Pakistan Punjab: Research on Equity and Variability at the Distributary Level

Muhammad Nawaz Bhutta and Edward J. Vander Velde

IIMI RESEARCH IN Pakistan on distributary channels is primarily concerned with how irrigation agencies can be effectively assisted to improve irrigation system performance at the secondary level, in order to achieve and sustain higher output from irrigated agriculture. Specifically, the research objective is to identify management options with the potential to increase equity and reduce variability in irrigation water deliveries, improving the performance of irrigated agriculture. This research is predicated upon two key observations. The first is that, so long as the irrigation environment is characterized by inequitable and unpredictable water deliveries, Pakistani farmers are unlikely to invest in improved farm management practices. Much research on farmer adoption of new or improved farm inputs and farming practices suggests that this assumption is not unreasonable. The second observation is that Pakistan irrigation agencies continue to cite distributional equity and the provision of adequate amounts of water at appropriate times — "so far as is possible" — as performance objectives for the public irrigation infrastructure that serves farmers.

Begun in 1987, this research has focused principally upon an analysis and understanding of the actual conditions of secondary canal operations in one major Punjab canal command, the Lower Chenab Canal (LCC) system [59]

Field studies have been carried out over several successive agricultural seasons to determine the relationship between existing water distribution conditions and design norms. Field research has also sought to identify the forms and extent of management activities currently practiced in representative areas of the LCC system, keeping in mind that in so large a system substantial spatial diversity is the norm.

Preliminary findings on the equity and variability of water deliveries between different distributaries, as well as among watercourses along Lagar Distributary in the

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[59] Perhaps a sense of scale of the LCC is best communicated by the following: its irrigable command area is more than 1.2 million ha, served by 176 distributary channels (excluding minors and sub-minors), the total length of which exceeds 2,800 km. Design full supply discharge for the system at head exceeds 310 cu.m/s.

LCC, were reported internally by IIMI Pakistan in November 1987. That report was based upon the analysis of primary water supply measurement data collected by IIMI Pakistan for the period August-October 1987, and of several years of secondary data provided by the Punjab Irrigation Department. Subsequently, summaries of additional findings have been presented in periodic research progress reports prepared by IIMI Pakistan for its Consultative Committee, donors, and internal institutional programs.

THE DISTRIBUTARIES OF THE STUDY

The following discussion is based upon primary measurement data covering both a much longer period of field research activity and an increased number of distributary channels. In the case of Lagar Distributary in Farooqabad Sub-Division, Upper Gugera Division, primary data are now available for nearly two years, from August 1987 through June 1989. Primary and secondary data are also available for three additional distributary channels in the LCC system where IIMI Pakistan field staff have been measuring and monitoring irrigation operations for the past three agricultural seasons. Table 11.1 provides basic information about the distributaries currently being studied in this research.

Table 11.1. Distributary characteristics.

Distributary	Design discharge (m^3/s)	CCA (ha)	No. of minors & sub-minors	No. of outlets	Design intensity (%)
Mananwala	5.24	27,159	4 (1)	125	50 & 75
Lagar	1.08	6,578	1	30	50 & 75
Pir Mahal	4.67	14,891	4	90	75
Khikhi	9.66	33,119	6 (3)	158	75

In April 1988, IIMI Pakistan expanded daily measurement activities of water conditions to include a set of locations along the primary channel of Mananwala Distributary, also in Farooqabad Sub-Division. In size and service area, Mananwala Distributary is arguably a "more typical" distributary of the LCC than is Lagar. There also appears to be an important incipient soil and groundwater salinity condition in its tail-reach command area.

Regular field observations and measurement activities had already been extended to a limited number of survey locations along both Pir Mahal and Khikhi distributaries in Bhagat Sub-Division, Lower Gugera Division, in November 1987. The choice of Bhagat Sub-Division for these activities was conditioned by the need to maintain system contiguity, by the desirability of including a known contrasting hydrologic environment in this research, and by the cooperation offered by the Punjab Irrigation Department.

Bhagat Sub-Division comprises the command of six distributaries in the southwestern portion of LCC (East) Circle, including four that offtake at the tail of Lower Gugera Branch canal. Surface water supplies here are rather less reliable than in sub-divisions served by Upper Gugera Branch canal. Unlike Farooqabad Sub-Division, public tubewell systems are largely absent; moreover, groundwater is often too saline for irrigation purposes unless it is mixed with canal water. Finally, rotational operations both between distributaries and within distributaries are commonly practiced in Bhagat Sub-Division.

Mananwala Distributary is 45 km in length, and surface flow observations and measurements are carried out at 20 points confined to the main distribution channel; no watercourse observations have been made along its minor channels. Monthly crop surveys of sample fields in five watercourse commands, and daily monitoring of public and private tubewell operations in these same commands, supplement IIMI surface water data.

Lagar Distributary is a much shorter channel (19 km). Surface flow conditions were measured and observed daily at 28 locations along the distributary and its minor until the end of rabi season 1988-89. These data are now generated from the hydraulic model, MISTRAL, adapted for Punjab canal applications and thus far calibrated only for Lagar. Additional data collected in Lagar command include detailed monthly crop surveys in 3 watercourse commands and daily logs of all public and private tubewell operations in 13 watercourse commands.

Pir Mahal Distributary is slightly longer than Mananwala at 48 km but its service area is a good deal smaller because of a higher design water allocation. Along Pir Mahal, beginning in late 1987, surface water conditions were measured at 30 locations through rabi season 1988-89, after which the observation points were reduced to 23. Irrigated agriculture activities, as well as private tubewell operations are monitored in six watercourse commands.

Khikhi Distributary is the largest on which IIMI is conducting research, although it is only 43.5 km long. Regular observations and measurements of surface water distribution are presently confined to its head and the offtakes of its principal minors. This is because the phased rehabilitation program of canal lining — the primary reason for Khikhi's selection as a study channel — underway since early 1988, means flow conditions are unstable for about six months per year.

In summary, IIMI Pakistan's detailed field observations of secondary-level irrigation operations in the head reach and the tail reach of a very large Punjab canal system now cover a range of conditions of management actions by, and options available to, Sub-Divisional Officers and Executive Engineers, the agency officers primarily responsible for day-to-day canal operations. It is perhaps significant that the LCC system has also been considered by many agency and government officials to be one of the better operating systems in Punjab, although the sociopolitical environment dominant in the command area of Upper Gugera Branch is reckoned to be possibly the most difficult and violent in the province.

PUNJAB CANAL SYSTEMS AND EQUITY

The equity principle that the Punjab Irrigation Department has sought to maintain in canal operations was originally established as a design parameter for Punjab canal systems. An amount of water was to be made available at the head of each *moghu* (watercourse outlet) for its command area based upon a preset "duty" or water allowance per unit area. Two standards were followed in the design of the LCC system. Outlets that served preexisting settlements and their agricultural lands were allocated 1.9 cusecs (53.8 l/s) of water per 1,000 acres (405 ha) of culturable commanded area (CCA, the physically irrigable agricultural area commanded by the outlet) or about 1 l/s per 7.5 ha. Moghas serving the agricultural lands of new villages were designed to deliver water at the rate of 2.84 cusecs (80.4 l/s) per 1,000 acres CCA (about 1 l/s per 5 ha). Design discharge at the outlet is therefore directly related to irrigable area commanded by the outlet, and each unit of irrigable area within the outlet command is allocated an equal share of surface water. Since the amounts of water allotted to area units in perennial canal systems were very low (at the turn of the 20th Century, the irrigation development objective was to protect maximum spatial extent from rainfall failure and famine, not to maximize productivity per unit of land), it was further envisaged that the actual area irrigated by farmers in any year of two agricultural seasons would not exceed 50 percent of the CCA in the former instance or 75 percent of the CCA in the latter case.

Furthermore, the large Punjab canal systems were designed and constructed with a minimum of adjustable control structures throughout the main and secondary system. For example, below Sagar Head, the Upper and Lower Gugera Branch system of the LCC, designed to carry about 170 cu.m/s at full supply, has only a single movable crossregulator in its 250 km length. Below the distributary head gate, water is distributed to the watercourses through fixed structures or moghas, either an orifice or flume, at their heads.

Unquestionably, there have been many changes in the 90 or so years since the LCC system began operations. By no means the least of these was the introduction, in the early 1960s, of an extensive large capacity public tubewell infrastructure (SCARP I) in the upper half of its command area, which often tripled or even quadrupled water supplies at the watercourse head. Nevertheless, the water allocation principle for the surface system remained as originally designed, and the performance objective for canal operations continues to be the delivery to each outlet of its sanctioned share of the distributary's full discharge. Since the outlets are fixed structures, the relationship between its design discharge and the water supplied to each watercourse head along the distributary is governed primarily by hydraulic principles.

If the performance objective is to be achieved, then stable distributary water levels at, or very close to, design levels are required, because departures from design levels will cause differences in outlet discharges. The standard and most widely used orifice outlet, the APM, maintains a proportional head-discharge relationship to about 70 percent of channel design discharge. Rotational operations between distributaries are planned for use when system water supplies are insufficient to maintain canal discharges above 70 percent of design. Although routinely drawn up, rotational

programs are rarely adopted, perhaps because it is widely assumed or perceived that Punjab canal systems operate continuously at, or near to, full supply levels throughout the main and secondary channels.

DISTRIBUTARY PERFORMANCE: WATER DISTRIBUTION EQUITY

An early research finding on Lagar Distributary was that the degree of maintenance required to keep channel conditions reasonably close to design was not being achieved. Not only was the distributary significantly silted, particularly in the head reach and downstream of Jhinda Minor offtake, but its cross-section was substantially enlarged in many reaches and the embankments severely eroded in numerous locations throughout its length, despite having been rehabilitated in 1985 when the tail one-third of the channel was lined. Figures 11.1 and 11.2 illustrate the difference between design and existing physical conditions for Lagar in late 1988.

Consequently, the existing full supply water level was substantially above the design level for nearly the upper two-thirds of the channel. Subsequent field survey work on Pir Mahal and Mananwala distributaries revealed very similar physical conditions for these channels, too. The implication is that the inability to sustain required levels of channel maintenance has led to an increasingly widespread deterioration in the

Figure 11.1. Lagar Distributary: Longitudinal section (RD 0 to RD 32).

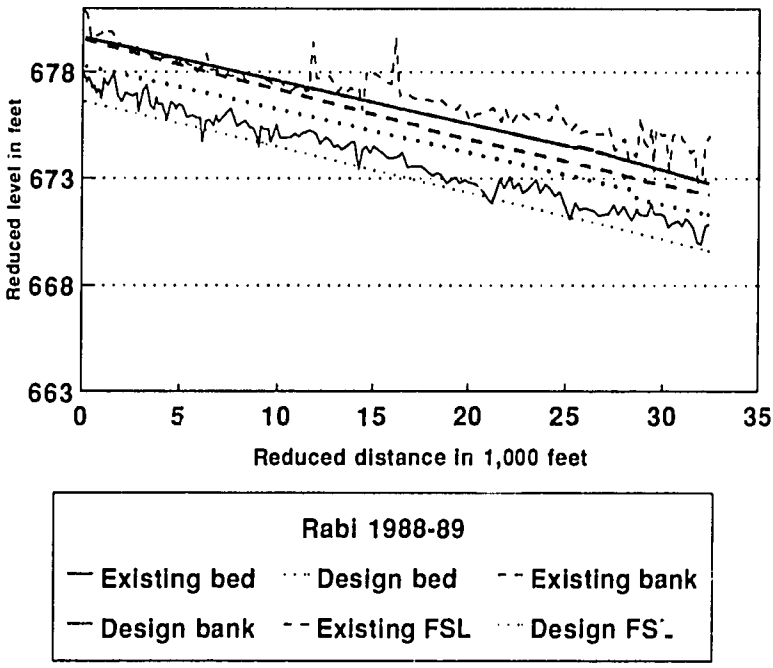
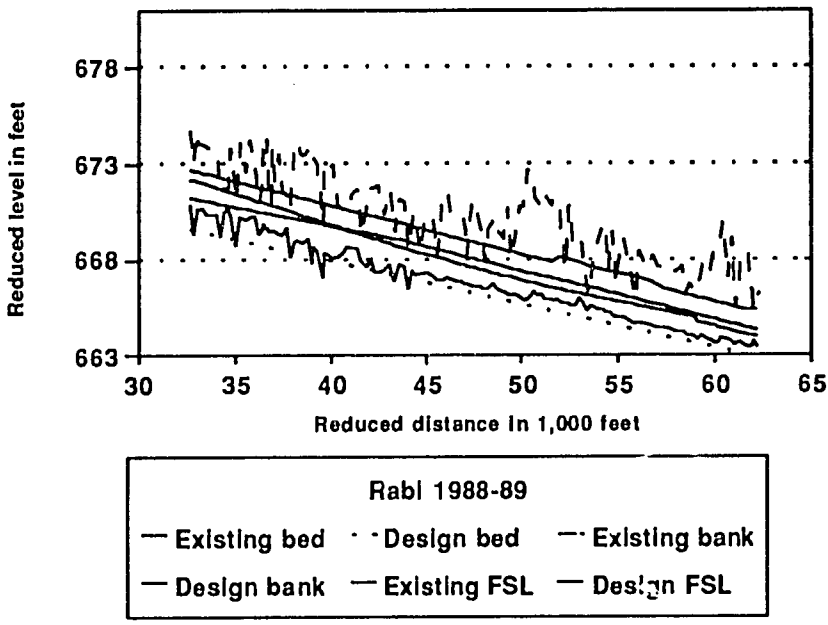


Figure 11.2. Lagar Distributary: Longitudinal section (RD 32 to RD 62).



physical conditions of distributaries throughout the LCC and, quite likely, in other Punjab canal systems as well.

One consequence of continuing low levels of maintenance inputs to secondary channels is that the relationship between design and actual discnarge conditions at the heads of watercourse outlets is dominantly a function of the physical distance between an outlet and the distributary head gate. This is illustrated by the markedly similar patterns of water distribution equity among outlets for Lagar (Figure 11.3) and Pir Mahal (Figure 11.4) distributaries under near-design discharge conditions. The term used here to describe this relationship, Delivery Performance Ratio (DPR), is the ratio of actual discharge to design discharge. When the relative distance measure developed by Murray-Rust (IIMI Review Vol.2 No.1 April 1988, pp 17-18) ("Equivalent Distance" — a measure which combines actual distance and the locational opportunity of an outlet vis-a-vis channel discharge) is applied, the difference between actual and design conditions is even more strongly related to an outlet's location along the channel (Figure 11.5).

When distributary head discharges fall below 70 percent of design, DPR for the last quarter to one-third of watercourse outlets rapidly approaches zero. At discharges below 50 percent of design, most outlets in the lower half of distributaries do not draw any water at all (Figure 11.6). These relationships have been known for decades, and the management option of rotational operation of distributaries was framed partly to minimize inequity in water distribution under such low water supply conditions. Interestingly, however, a rotational delivery program between and within distributaries has so far been implemented only in Bhagat Sub-Division, despite the fact that head

Figure 11.3. Lagar Distributary: Water distribution equity.

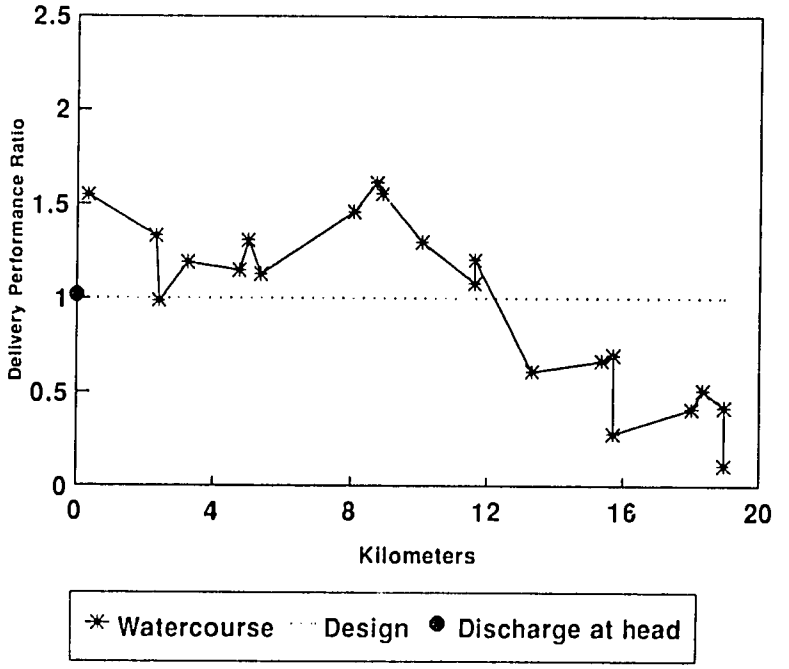


Figure 11.4. Pir Mahal Distributary: Water distribution equity.

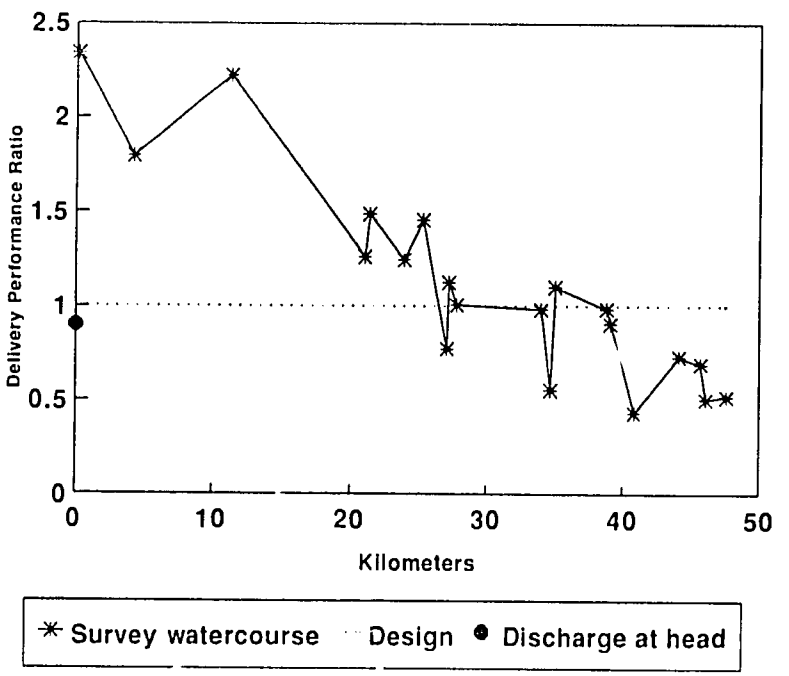


Figure 11.5. Lagar Distributary: DPR and equivalent distance.

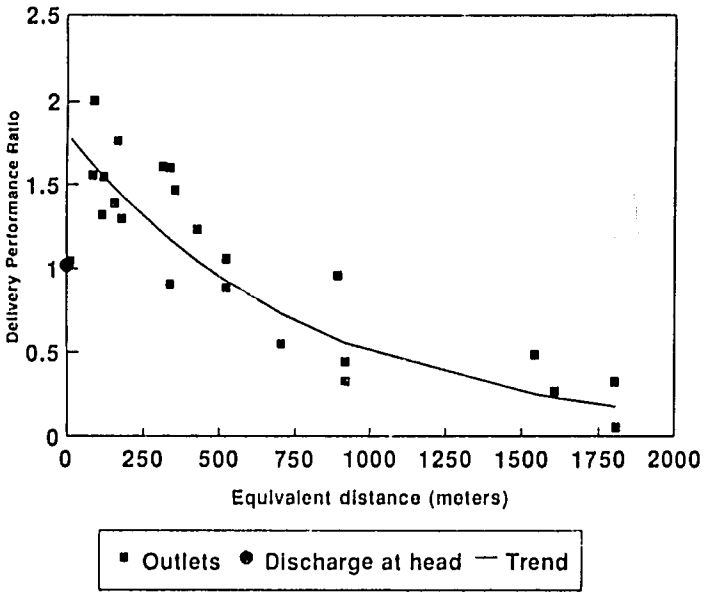
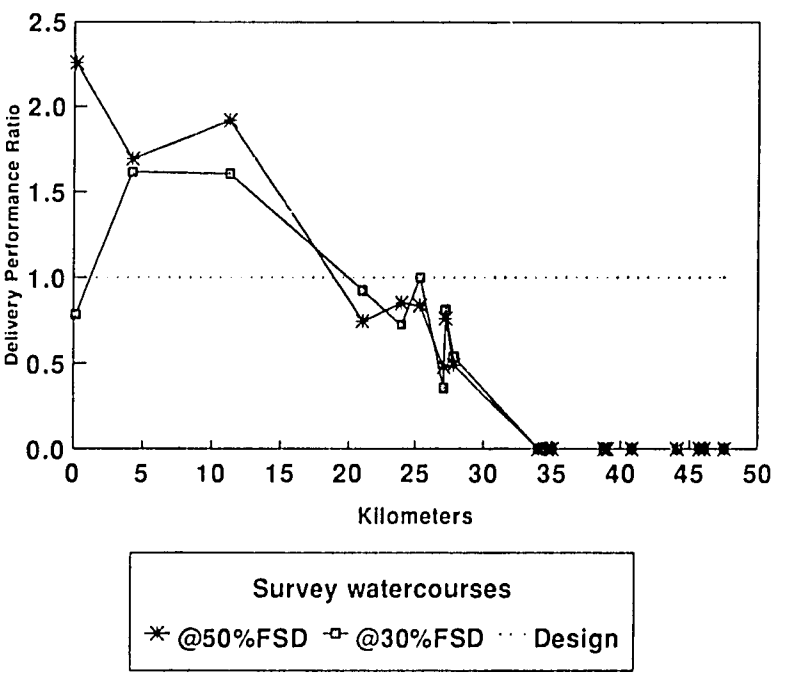


Figure 11.6. Pir Mahal Distributary: Water distribution equity, low Qs.



discharges of less than 70 percent commonly occur among distributaries in Farooqabad Sub-Division, too.

It is obvious that, on average, outlets in the tail reaches of distributaries draw only a fraction of their intended discharges, while those watercourses located in the upper half of the channel commonly obtain 25 percent to 50 percent more water than originally planned. The resulting pattern of water distribution inequity between watercourses along distributaries is both persistent and severe. Moreover, there appears to be relatively little variation in this pattern in terms of distributary location in the system. The long-term mean monthly DPR for Lagar (Figure 11.7), a distributary in the upper LCC, is little different from the long-term mean monthly DPR of Pir Mahal (Figure 11.8), a tail-end distributary in the system.

The degree of inequity experienced by irrigators is perhaps most readily demonstrated through the interquartile ratio (IQR), a measure suggested by Abernethy in 1986, that compares the performance of the poorest performing quartile of watercourse outlets to the top quartile along a channel. The measure has been modified and used here both for all outlets in each quartile length of a distributary (e.g., Lagar) and for all sample outlets in each distance quartile (e.g., Pir Mahal). IIMI data suggest that the DPR of upper quartile outlets is generally at least 4 times better than those in the lowest quartile (Figure 11.9 and Figure 11.10). This level of inequity largely explains the intensity and near-continuous frequency of complaints of tail-end Punjab farmers that they do not receive their fair share of canal water.

Figure 11.7. Lagar Distributary: Water distribution equity.

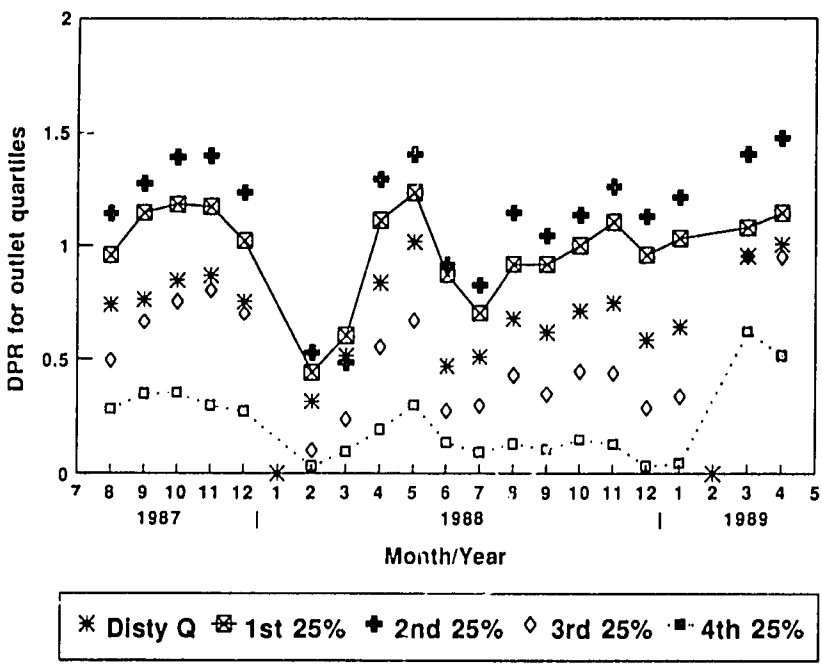


Figure 11.8. Pir Mahal Distributary: Water distribution equity.

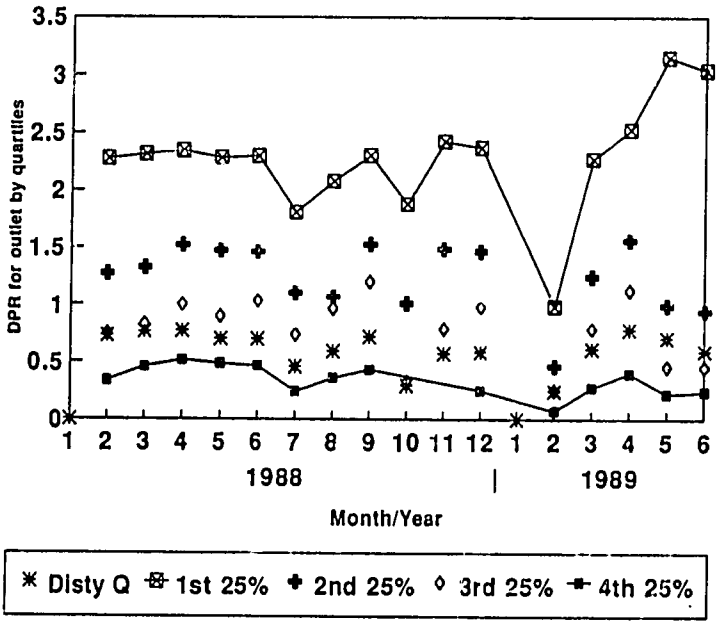


Figure 11.9. Lagar Distributary: Water distribution equity.

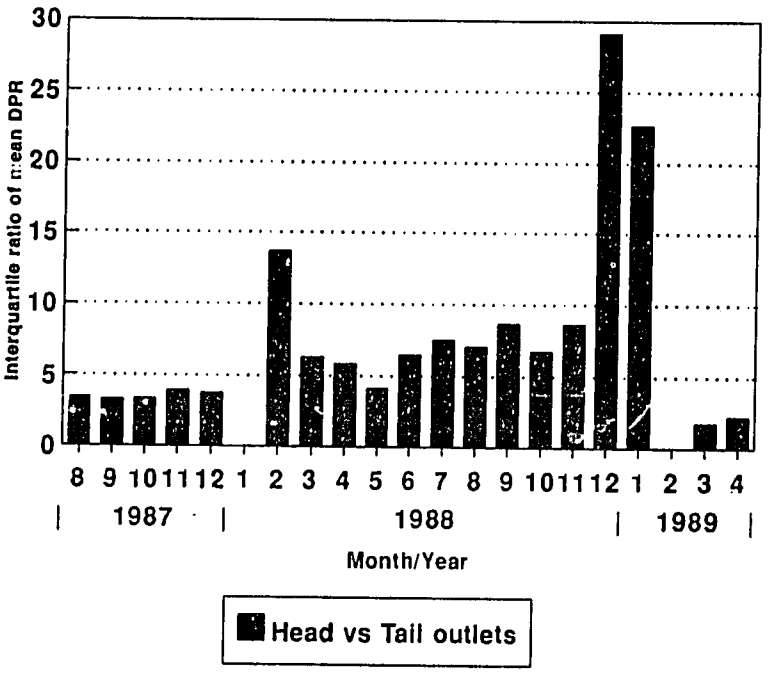
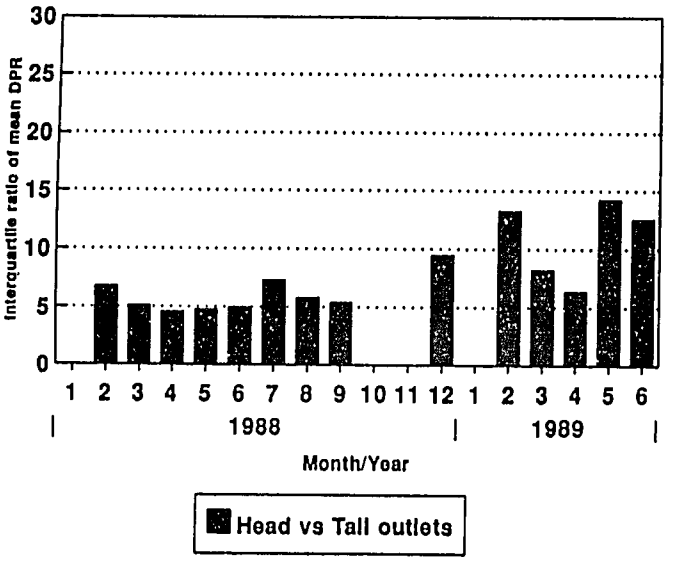


Figure 11.10. Pir Mahal Distributary: Water distribution equity.

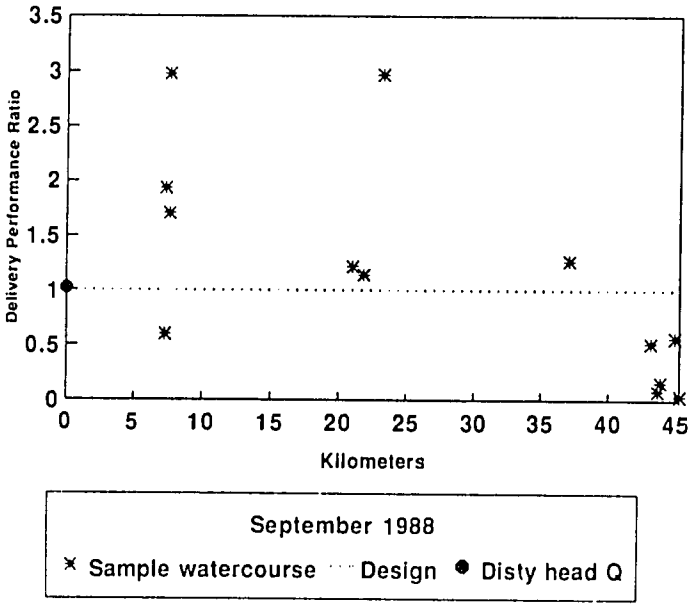


No ratio for October-November, 1988
as floods closed tail outlets

Although distributary-level inequity in water distribution is substantially accounted for by high rates of channel sedimentation and concomitant low levels of maintenance inputs, there are at least four other factors that interact to exacerbate this condition. The best known and most widely acknowledged of these variables are "outlet tampering," activities that result in a physical modification of the outlet structure so that it will draw more than its design or fair share discharge, and water theft, often through semi-permanent and/or quasi-sanctioned pipes and siphons. These interventions are widespread (increasingly so according to both agency officers and farmers), invariably concentrated in the upper two-thirds of distributaries, and are difficult, though not impossible, to track. It is not uncommon for farmers and agency field staff to be jointly involved in activities, and for both to benefit from them.

The impact of these factors is revealed on Mananwala Distributary where such interventions have been more commonly observed by IIMI field staff than elsewhere in the LCC (Figure 11.11). This graph, a summary performance "profile" showing mean DPR for IIMI sample watercourses of Mananwala, covers a two-week period in late September 1988. In the upper reach of the distributary, a semipermanent, quasi-sanctioned tampered outlet is shown drawing nearly three times its design discharge under full supply conditions, a performance level consistently observed there since studies began on this distributary. A second outlet about half-way downstream has recently been illegally tampered with; it too draws about three times its design discharge, much more than previously observed under similar distributary discharge conditions. A third intervention can be inferred from the virtual collapse of tail outlet

Figure 11.11. Mananwala Distributary: Mean DPR for sample water courses.



DPR for the period. Field observations and interviews, however, revealed that at several locations about 30 kilometers down the channel farmers had intervened at night during these two weeks to redirect much of the distributary flow through embankment cuts into a temporary network of nine watercourses to irrigate fields of rice!

A third contributing factor to distributary-level water distribution inequity is, ironically, the watercourse improvement program of the Directorate of On-Farm Water Management (OFWM) which has as a principal objective the enhancement of water distribution equity within the watercourse command. Certainly the impact thus far observed is unintended, but it is significant nevertheless and is in large measure a consequence of the pronounced bias in the spatial distribution of watercourse improvement within distributary commands. A primary component of the OFWM program is watercourse lining, which frequently involves the restoration of an appropriate bed slope to the channel. In many instances the result is an improved watercourse discharge, usually because the flow condition at the mogha is changed from non-modular to modular, which is, of course, the design outlet flow condition. However, when this occurs for watercourses in the upper reach of a poorly maintained distributary, the frequent result is an outlet discharge greater than sanctioned (because of a higher than design water level in the distributary), and a concomitant reduction in downstream distributary discharges.

Unfortunately for distributary water distribution equity, there has been a very strong "top-end" orientation to the implementation of the OFWM watercourse improvement program. A survey of all watercourses of distributaries in Farooqabad Sub-Division, done in 1988-89, showed that just under 40 percent of the total had been partially lined

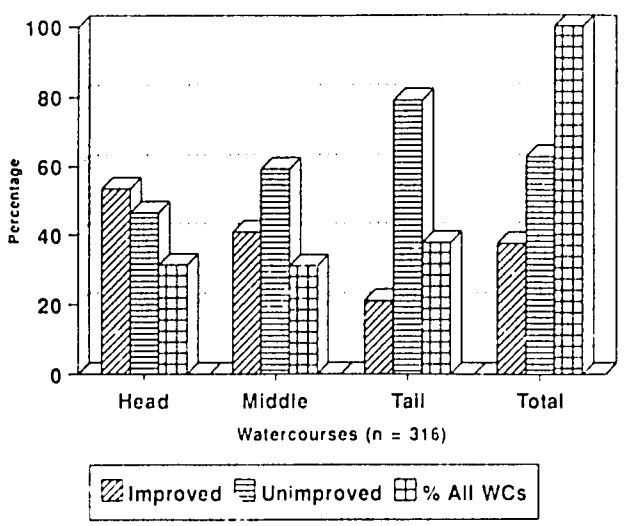
through the OFWM program (Figure 11.12). More than one-half of the watercourses in the head reaches of these distributaries had been improved as had slightly more than 40 percent of the watercourses in the middle reaches. By contrast, nearly 80 percent of tail-reach watercourses had not been improved, despite the fact that more watercourses are located in the tail than in either the head or middle reaches of Farooqabad distributaries.[60] A comparable pattern of spatial bias is found among the 131 watercourses in the command of Khikhi and Pir Mahal Distributaries of Bhagat Sub-Division, even though this locale was one of the first to be targeted when the watercourse improvement program was initiated province-wide in the late 1970s.

Every lined (i.e., "improved") watercourse on Lagar Distributary typically has a DPR 25 percent to 50 percent greater than the corresponding DPR at distributary head; all are located within the upper two-thirds of the channel. Lined watercourses among IIMI survey outlets in the top two-thirds of Mananwala and Pir Mahal distributaries exhibit a similar DPR relationship.

The last, though by no means least, contributing factor is the frequency of distributary operations under low discharge conditions. Operational data for 1988 and 1989 confirm that the distributaries under study typically operate at less than 75 percent of design discharge for between 70 and 160 days per year, excluding the annual maintenance closure period of 3 to 6 weeks. There are a variety of reasons for this operational mode, some of which are generic, others more channel-specific, and still others remain to be clarified.

When Upper Gugera Branch canal operates at or below 75 percent of full supply, Mananwala and, particularly, Lagar operate at less than 50 percent of their design

Figure 11.12. Farooqabad Sub-Division distributaries: Distribution of watercourse improvement.

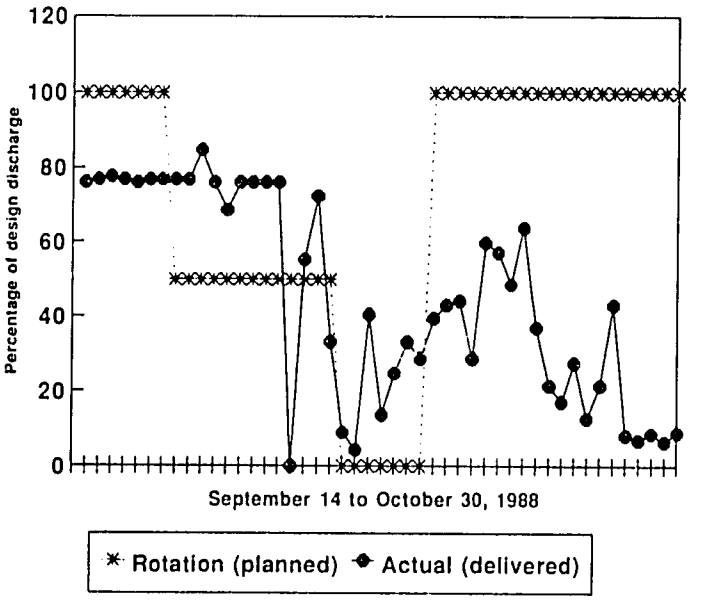


Field Survey Data, 1988-89

[60] The probability of such a pattern having emerged by chance is less than 0.001.

discharges. The lower half of Pir Mahal was severely damaged by river flooding in early October 1988, and it took an unusually long time for repairs to the channel to be effected. It therefore operated for about 60 days at a greatly reduced head. Moreover, for another 62 days, discharge into the distributary was reduced or stopped as part of the rotational program between distributaries in Bhagat Sub-Division. The resulting pattern of low discharges for Pir Mahal is partially illustrated in Figure 11.13.

Figure 11.13. Pir Mahal Distributary: Rotational program at head.



In all distributaries, flows are diminished or terminated for brief periods to carry out urgent maintenance, to repair breaches in the channel, or because farmers have indicated that they do not need water for their crops. No gatekeeper/gauge observer has a reliable, up-to-date rating table to guide him in gate adjustments, so there is some lag in their responses to changing main channel flow conditions. Only Mananwala Distributary is equipped with a readily adjustable mechanical gate in any case. What is not known, because of the relatively short time span for which data are available and the limited sample size of four distributaries from a single system, is just how widespread and persistent this operational pattern is in the Punjab.

DISTRIBUTARY PERFORMANCE: VARIABILITY IN WATER DISTRIBUTION

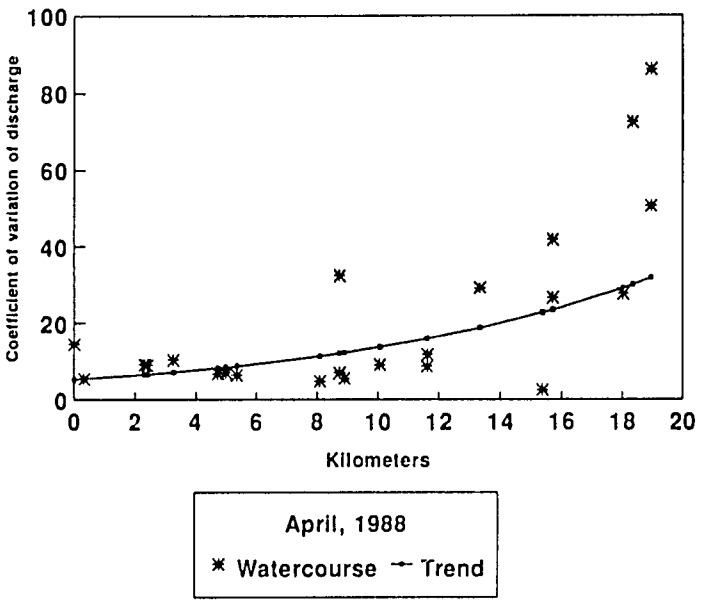
Variability of surface water supplied to the heads of outlets along distributaries exhibits a general spatial pattern that parallels that of equity in water distribution. Distributary

conditions that produce serious inequity in water distribution between head and tail also tend to magnify water supply variability between these locations. The close correlation with distance, in this case increased variability of discharge to outlets with increasing distance from the distributary head, is generally pronounced for all distributaries, whether at the head of the LCC system or the tail. Distributary profiles of outlet discharge variability for the same month and similar head discharge conditions for Lagar (Figure 11.14) and Pir Mahal (Figure 11.15) illustrate this pattern.[61]

Certainly this relationship is logical and consistent with expectations, especially given the hydraulic conditions of channel flows previously described. As the amount of discharge in the channel diminishes toward the tail reach, relatively modest fluctuations in water supplies at the distributary head that are uncontrolled and transmitted downstream in a rigidly designed system become a significantly larger fraction of the remaining discharge.

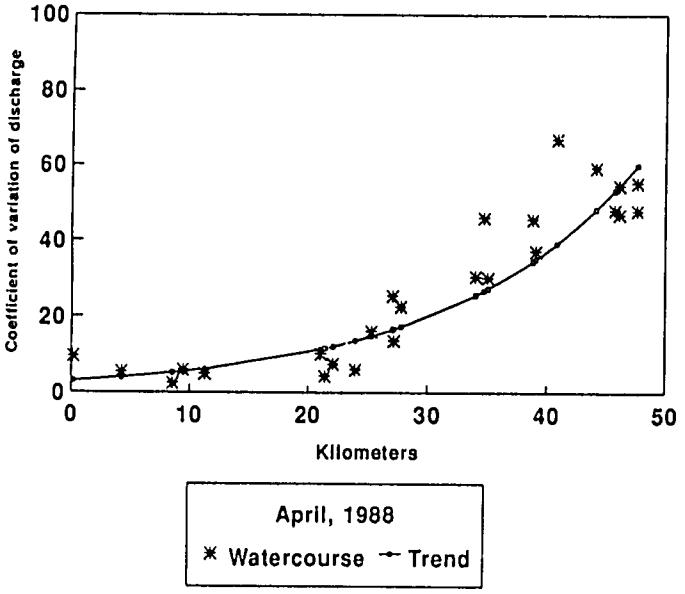
However, there are also important and rather distinctive differences in water distribution variability among the distributaries studied, apparently related to more site-specific operational conditions. These include the presence or absence of a readily adjustable head gate and the activities of gatekeepers. As was noted previously in IIMI Pakistan's 1987 reporting of preliminary research results, it is common to encounter outlets where water flows fluctuate between modular and non-modular conditions,

Figure 11.14. Lagar Distributary: Variability in outlet discharge.



[61] Here and elsewhere in the discussion that follows, the coefficient of variation, a measure of relative variability or dispersion around a mean condition, has been used to ascertain variability in water distribution.

Figure 11.15. Pir Mahal Distributary: Variability in outlet discharge.

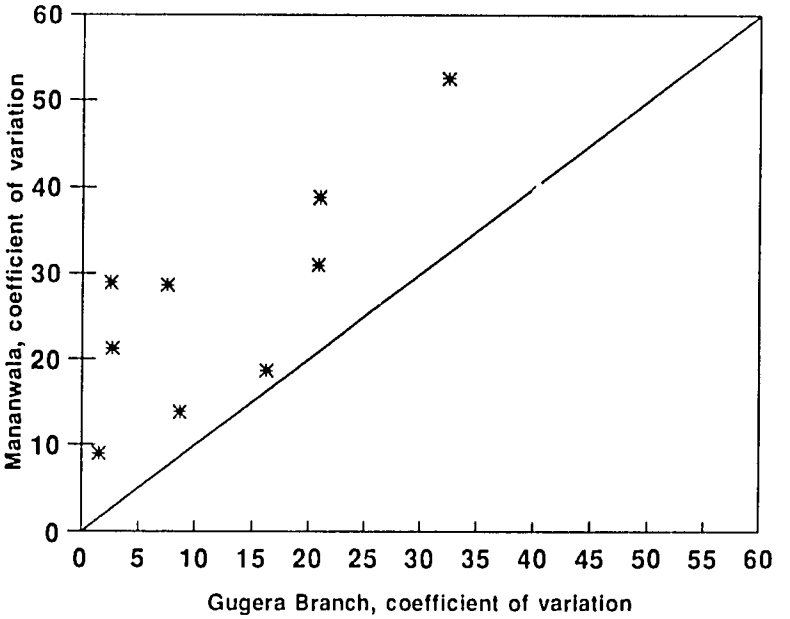


particularly in the upper reaches of distributaries. In addition to changing distributary water supply levels, the presence of a large public tubewell discharging into the watercourse head can be a cause of this condition. Farmer activities below the outlet, such as irrigating higher fields during their warabandi (roster) turn along the watercourse, poor watercourse maintenance, or improperly designed or implemented watercourse improvements, have also been observed as factors contributing to water distribution variability.

Mananwala Distributary is the only distributary currently being studied that has a mechanical head gate. Lagar's head gate is comprised of stop-logs (horizontal karries) and at Bhagat (the tail of Lower Gugera Branch), vertical karries are used to regulate discharges through the proportional dividing head structure into Pir Mahal Distributary. In neither of the latter two cases is it as easy to adjust the head gate to respond promptly to main channel flow fluctuations as it is in the former.

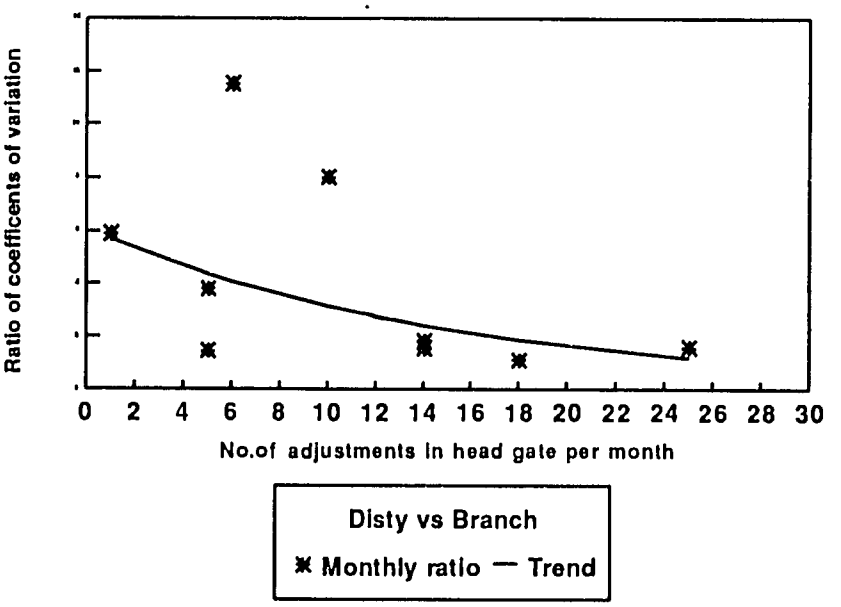
Analysis of a limited set of discharge and gate operation data for Mananwala Distributary reveals that with careful and frequent head gate adjustments, variability in distributary head discharges relative to the variability of main channel discharges can be successfully managed. This is shown in Figures 11.16 and 11.17 where the coefficients of variation of monthly main channel and distributary head discharges are plotted, and then the ratio between Mananwala variability and Upper Gugera Branch variability is compared to the number of adjustments made monthly in the distributary head gate. The kinds of information used by the gatekeeper to make the adjustments, as well as the reasons for many adjustments being made in some months but not in others (thereby resulting in more variable distributary flow conditions), remain to be identified.

Figure 11.16. Mananwala Distributary and Gugera Branch: Monthly discharge variability at head.



April - December 1988

Figure 11.17. Mananwala Distributary: Head gate operations vs discharge variability of Mananwala and Upper Gugera Branch

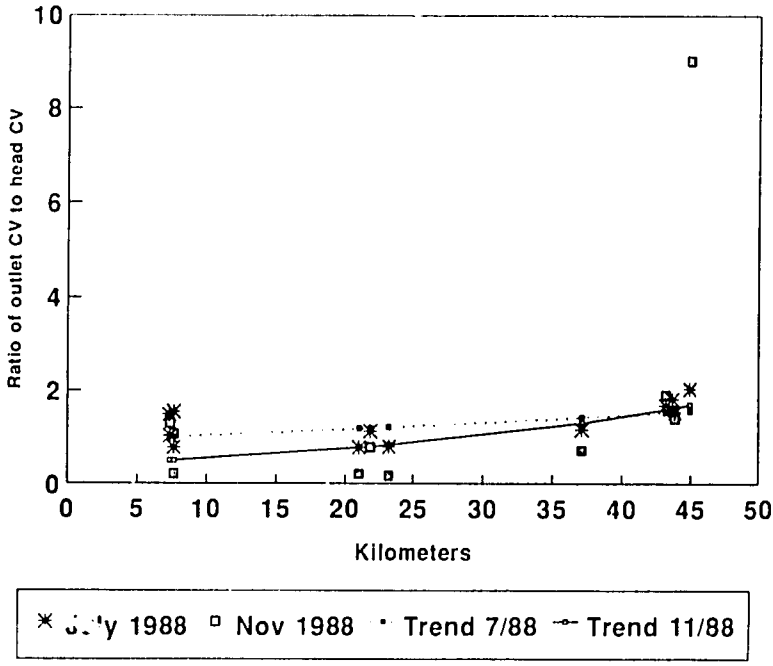


IIMI data, April- December 1988

The likely consequences of such gate management can be inferred from Figure 11.18. The month of July 1988 was the month of maximum variability in Upper Gugera Branch flows, as well as of maximum head gate adjustments. In November 1988, variability in Upper Gugera Branch flow was less than 5 percent, although variability of Mananwala discharges at head was nearly 30 percent, about 50 percent less than that of July 1988. Overall, the condition of relative discharge variability at watercourse heads down Mananwala for these two months was roughly the same, as indicated by the computed trend lines for these two months. This would suggest that variability in main channel flow was managed rather effectively in July, and was not passed into the distributary to further exacerbate flow conditions.

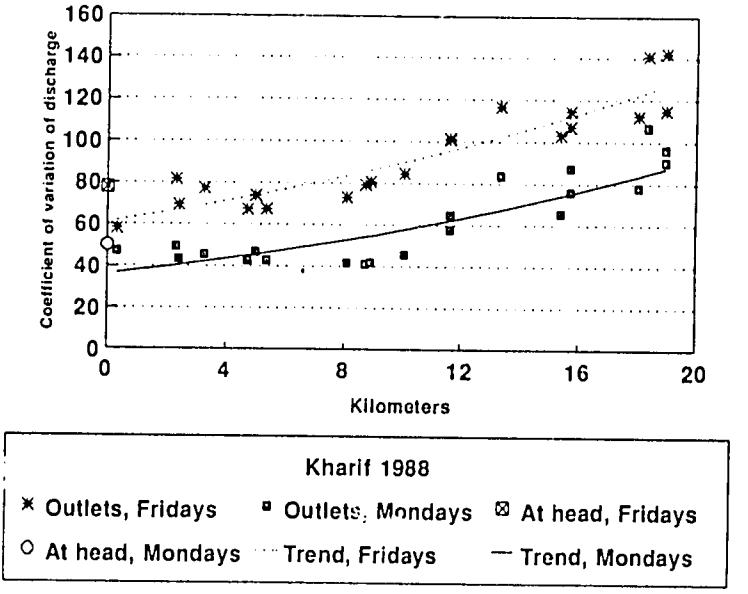
Analysis of daily discharge conditions for Lagar Distributary outlets during 1988 indicates that there may be a significant diurnal pattern to distributary discharge variability that compounds the problems of surface water supply reliability to which farmers must adjust. Water supply variability for Fridays at the head and along the distributary (Figure 11.19) during kharif season, 1988, for example, was consistently about 50 percent greater than variability on Mondays.[62] Concomitantly, DPR for

Figure 11.18. Mananwala Distributary: Gate operations and outlet Q variability.



[62] Although a "Friday effect" on operations of Pakistan's canal systems has been speculated about by some observers, this is the first firm evidence that such a condition may indeed exist. Fridays, as well as half of Thursday, are the "weekend" in Pakistan and thus a time when agency officers and staff are normally not at work.

Figure 11.19. Lagar Distributary variability: Discharge at outlets on selected days.



Mondays equalled or exceeded that of Fridays for about 85 percent of the season, a period of maximum crop water requirement and, correspondingly, of maximum water demand by farmers.

Such a pattern of discharge variability interpenetrating the pattern of water distribution equity has important implications for actual surface water supply conditions encountered by farmers in their watercourses where farmers' irrigation turns are governed by the common 7-day warabandi[63]. Typically, the warabandi cycle begins on Monday mornings with the irrigation turns of farmers whose lands are at the watercourse head. In this roster of irrigation turns, farmers whose turns come on Fridays are commonly those whose lands are more than half-way down the length of the main watercourse. The extremes in the diurnal pattern of DPR variability at watercourse head encountered by farmers in mid-kharif 1988 in two watercourse commands, one a head outlet and the other a tail outlet, on Lagar Distributary are depicted in Figures 11.20 and 11.21, respectively (note the difference in DPR scale used in each figure).

Clearly, farmers whose irrigation turn comes on Mondays can anticipate both a greater likelihood of flows and a better flow condition than can those with Friday turns, just as all farmers served by head-end outlets can expect a better overall delivery performance by the channel than can those supplied by tail-end outlets. The cause(s)

[63] The 7-day warabandi is followed in the commands of 17 of the 23 watercourse outlets along Lagar Distributary's main channel.

Figure 11.20. DPR variability in Head Outlet 2R, for selected weekdays.

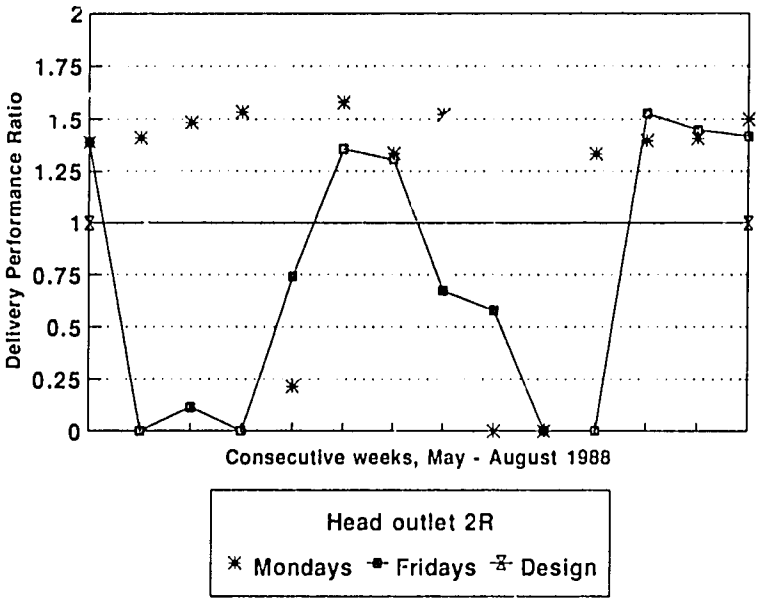
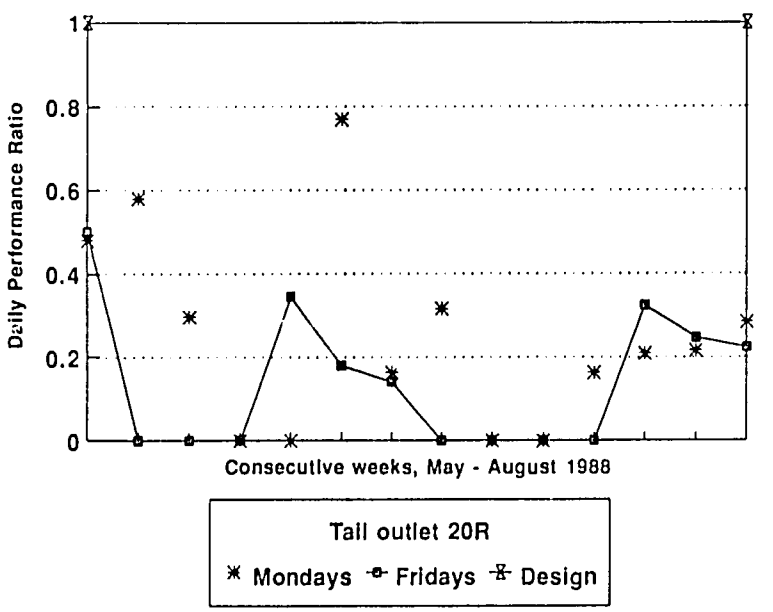


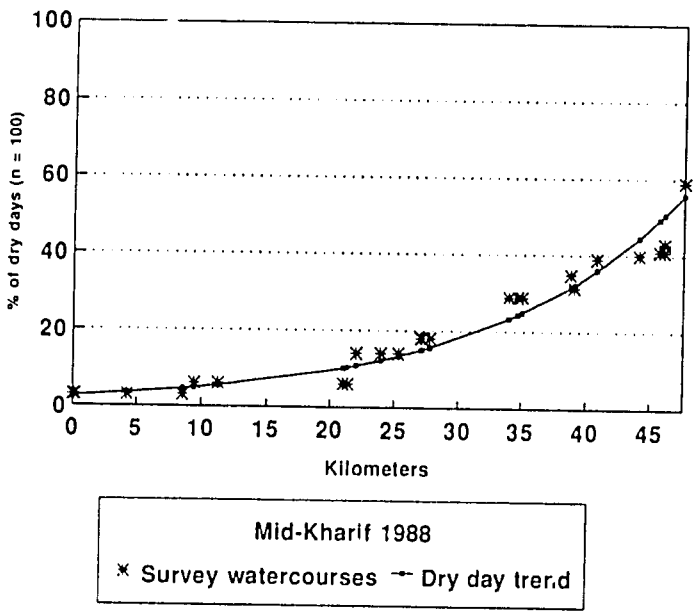
Figure 11.21. DPR variability in Tail Outlet 20R, for selected weekdays.



of this diurnal pattern in Lagar, and whether or not it is common to other distributaries (and in other systems) can only be speculated about at this juncture. It has not, as yet, been identified for Mananwala Distributary in the same sub-division.

Neither has such a pattern been observed in the operations of Pir Mahal, where the interaction of both between-distributary and within-distributary rotations, currently being studied there, may mask its occurrence. In any case, rotational operations complicate the determination and analysis of variability in distributary water deliveries, insofar as low water or no water conditions are certain to be present periodically. Undoubtedly the within-distributary rotation practiced on Pir Mahal is a contributing factor to the disproportionately greater frequency of dry days at tail outlets than at middle or head outlets (Figure 11.22).

Figure 11.22. Pir Mahal Distributary: Dry days (percent).



MANAGEMENT OPTIONS TO IMPROVE WATER DISTRIBUTION EQUITY AND VARIABILITY

The primary objective of research on water distribution equity and variability at the distributary-level has not merely been to define the current condition and its causes in different canal systems in different agro-ecologic and hydrologic environments in Pakistan, but rather to identify appropriate management solutions to such problems that can be used by irrigation agencies. In the discussion that follows, some promising management opportunities to improve water distribution equity and lower water supply variability in distributaries are identified.

Improving Water Distribution Equity

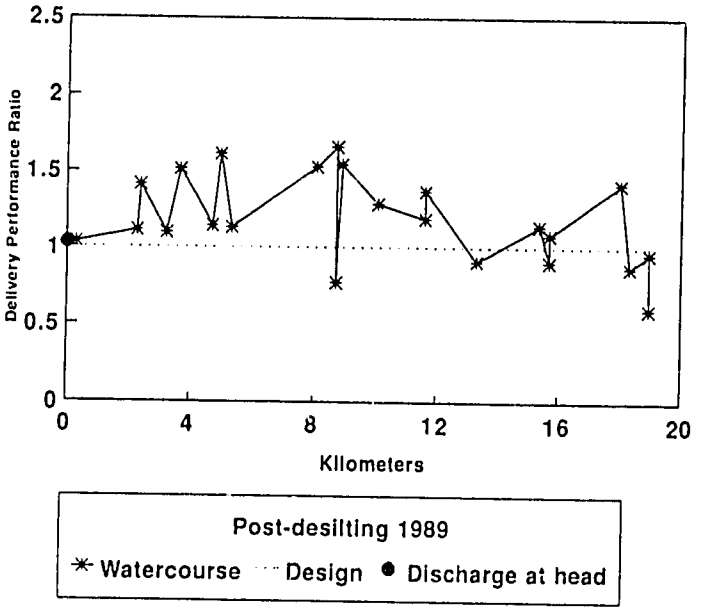
Formerly, when regular monitoring of watercourse outlets revealed that discharges had changed significantly, primarily in response to the changing physical condition of the distributary, a responsible officer (usually the Executive Engineer), would initiate procedures to remodel the channel and the outlets so that the existing distributary full supply water level resulted in a discharge that again met the design equity condition. Of course, if inspection showed that increased outlet discharges resulted from physical tampering with the structure, the outlet would be immediately restored to its former design and legal procedures would be initiated to identify and prosecute those responsible. It is widely admitted, however, that neither procedure to restore design water distribution equity conditions is — or can any longer be — practically followed by irrigation officers.

Consequently, improved management of regular maintenance inputs to distributaries is now the principal method whereby the Irrigation Department can readily redress serious water distribution inequity between watercourse outlets. The potential gains, as well as subsequent problems, of doing so were demonstrated on Lagar Distributary during the 1989 annual closure maintenance period. In a jointly planned and implemented "action" project, the Irrigation Department used survey and measurement data provided by IIMI to target channel desiltation and other channel maintenance activities to specific reaches of Lagar Distributary. The maintenance objective, of course, was to improve distributary performance, particularly in terms of increasing water distribution equity.

The performance profile for Lagar (Figure 11.23) after its annual closure confirms that when maintenance inputs are targeted to the primary locational sources of problems, rather than to the locational source of problem complaints, as had been done in previous years, the result is a very substantial improvement in water distribution equity. The distinctive linear correlation between lower DPR and outlet distance from the distributary head was markedly weaker. In Figure 11.7, it can be seen that mean DPR for tail quartile outlets for March and April 1989 was much greater than it ever had been for any two-month period since mid-1987. Even under a flow condition of less than 70 percent of design, there was a greater degree of equity in water distribution to outlets than had been previously observed. Moreover, under full supply conditions, at least initially, the IQR of delivery performance between head-end and tail-end outlets had been reduced from more than 5:1 to about 1.3:1. Farmers served by tail outlets claimed that surface water supply conditions were better than they had experienced at anytime in the previous ten years, although such claims could not be independently confirmed by reliable data.

It is clear that by targeting, as well as prioritizing, maintenance inputs at the distributary level, it is possible for the Punjab Irrigation Department to meet, at least partially, two important irrigation management objectives. On the one hand, it can obtain significant improvement in the degree to which it meets the existing canal operations objective of water distribution equity. On the other hand, it can demonstrate

Figure 11.23. Lagar Distributary: Water distribution equity.



a responsible management of the admittedly meager resources available to it for the maintenance of canal system physical infrastructure.[64]

Unfortunately, at this juncture, there is no firm evidence that either management objective is being achieved at a satisfactory or desirable level. In fact, the interquartile ratios of mean DPR for both Lagar and Pir Mahal distributaries (Figures 11.9 and 11.10) suggest that the failure to manage maintenance inputs more carefully, can contribute to a worsening pattern of water distribution equity. In the case of Pir Mahal Distributary, the IQR of head to tail outlets since October-November 1988 (when major work was done to repair damage to the lower half of the canal caused by river flooding), has been much worse than it was for the preceding eight months. The DPR for Lagar tail outlets in the twelve months after substantial maintenance inputs during the January 1988 annual closure followed a similar pattern.

Equally problematic is the current level of management of maintenance resources, and this has important consequences for how long improvements in water distribution

[64] The 1989 budget said to have been available to the Executive Engineer, Upper Gugera Division (which includes Farooqabad Sub-Division) for maintenance activities during the annual closure period was Rs 300,000 or about $15,000 at that time. This amount was so small, relative to the needs of some 27 distributaries commanding more than 230,000 hectares (575,000 acres), that the Executive Engineer chose to simply divide it evenly among the three subdivisions comprising Upper Gugera Division. The ID-IMMI "action" maintenance activity was financed separately from funds directly controlled by the Chief Engineer, Faisalabad Zone. Slightly more than Rs 65,000 was budgeted for it.

equity can be sustained. Further developments in Lagar command have not provided much of a basis for optimism here. Within slightly more than four months from completion of the joint "action" maintenance project on Lagar, water supplies to outlets in the last quarter of the distributary had deteriorated so badly that farmers there filled in a 20-m length of channel in protest. IIMI field observations and measurements permit at least a preliminary identification of two crucial reasons for this development that have significant implications for similar management interventions designed to improve secondary canal performance. First, targeted maintenance was not implemented and completed as planned and approved, and second, initial improvements in water supply conditions led directly to illegal interventions by farmers and ID field staff in order to appropriate improved supplies at points of locational advantage on the channel.

Comparative analysis of longitudinal and cross-sectional survey data of "before" and "after" channel conditions, done as part of IIMI's commitment to the "action" project, indicate that only a modest fraction of the earthworks — desilting and berm cutting — that were planned and said to have been done, was actually carried out.

There can be little doubt that this was a major factor in the non-sustainability of the initial improvement in water distribution equity. It is not clear whether this result reflects local conditions of maintenance resource management or whether it is part of a more widespread pattern. However, there would seem to be at least an implied need for more effective supervision and management of contracted ID maintenance activities at both sub-divisional and divisional levels.

A spatial refocusing of the watercourse improvement program of the Punjab Department of Agriculture, implemented by the Directorate of On-Farm Water Management, is also likely to enhance conditions for achieving a more fair distribution of distributary water supplies. If priority emphasis were given to improving watercourses offtaking from the tail reaches of distributaries before improving those in the middle or head-end reaches, there would be less chance of improved outlet flow conditions actually intensifying inequity in distributary operations. Action research to test the efficacy of this approach could be readily designed and implemented with agency cooperation and collaboration. It is already clear that a management initiative that deliberately focused and encouraged improvement of tail-end watercourses would have the additional benefit of conserving surface water supplies in the genuinely water deficit areas of distributary commands.

Initial canal operations simulation research using the hydraulic model, MISTRAL, calibrated by empirical data obtained for LCC distributaries has included a comparison of the management option of rotational operations at the distributary level with existing operational practices for Lagar Distributary. Preliminary results indicate that there was a modest decrease in the discharges of offtakes in the upper two-thirds of the distributary, although most continued to draw more than their design or sanctioned amounts. More important, however, was the prediction of a very considerable (two to three-fold) increase in supplies to outlets in the lower one-third of the channel. Given that distributary hydraulic conditions do not vary substantially among Farooqabad Sub-Division channels, the tentative conclusion from this work is that equity in surface water distribution could be significantly improved by implementing carefully planned

and rigorously followed rotational operations at distributary heads in the sub-division during low discharge periods in the main Upper Gugera Branch channel.

Reducing Variability in Water Distribution

Research results confirm that careful management of head gate structures is necessary if distributary discharge variability is to be reduced to, and maintained at, the lowest practical levels consistent with the rigid hydraulic design conditions of the secondary canal system. This is neither new nor surprising. However, the efficiency of the gatekeeper is substantially a function of the hardware and software available to him. It does not appear likely that the hardware of existing distributary gate structures is going to be replaced or modernized on a major scale in Punjab in the foreseeable future, although individual, localized improvements are bound to occur. More realistically, if information were made more reliable, then better head-gate management could be reasonably expected from gatekeepers.

Sufficient distributary discharge measurement data are now available to conclude that there are significant differences between the amounts of water recorded as being discharged into distributary channels and actual discharges. Comparisons between official records and IIMI measurement data for Mananwala, Lagar and Pir Mahal distributaries are shown in Figures 11.24, 11.25 and 11.26 respectively. A major reason for this gap is that all gatekeepers (or gauge observers) in the two sub-divisions

Figure 11.24. Mananwala Distributary discharge: Comparison of ID records and IIMI data, August-September 1988.

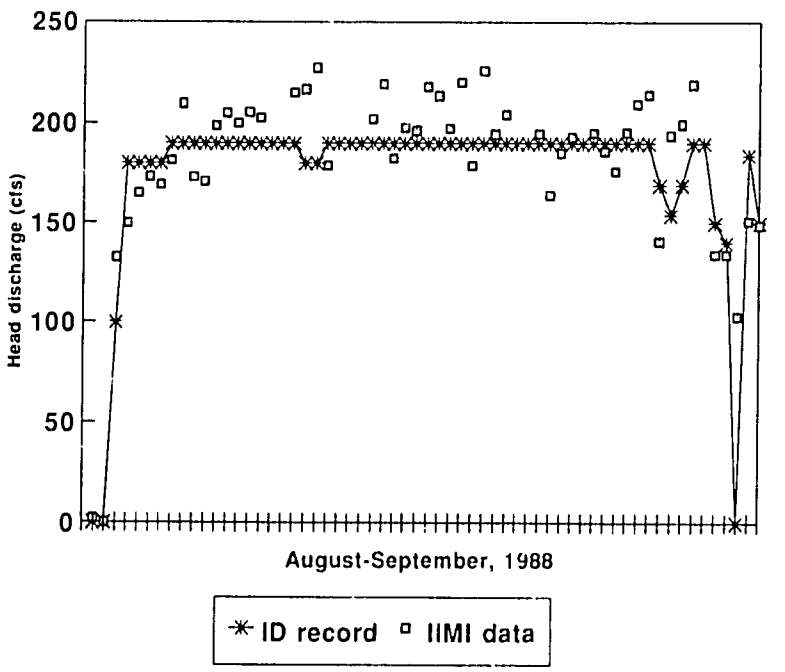


Figure 11.25. Lagar Distributary discharge: ID records and IIMI data, August-September 1988.

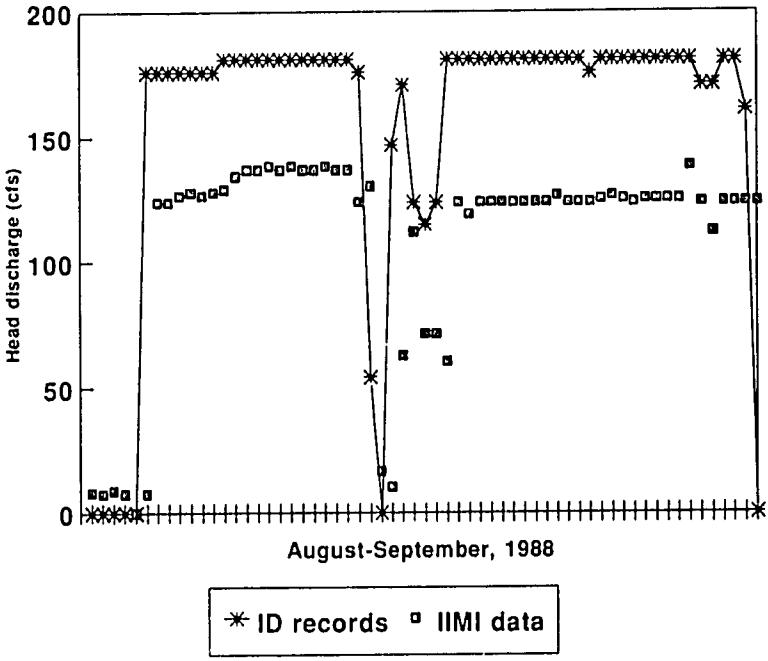
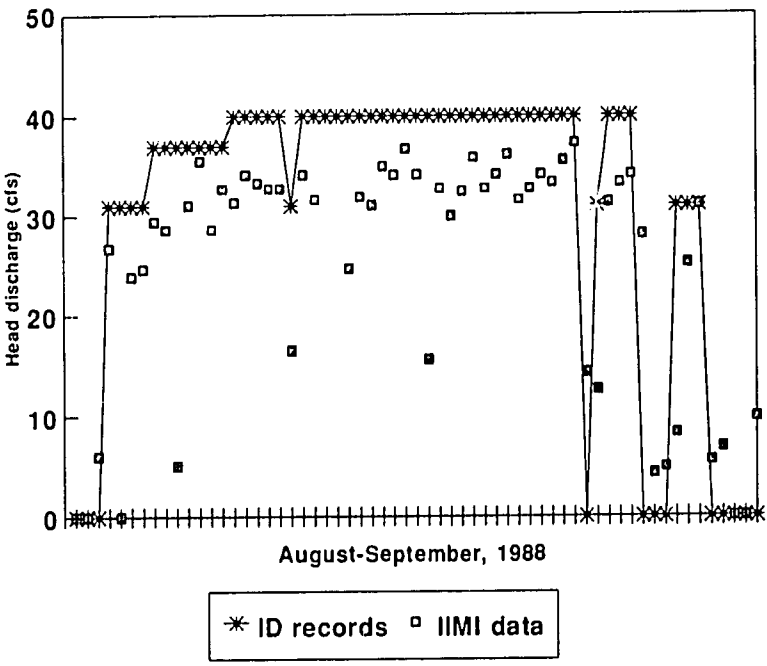


Figure 11.26. Pir Mahal Distributary discharge: Comparison of ID records and IIMI data.



where research is underway are using discharge tables for their structures that are often more than 20 years old. When this condition is combined with the absence of gauges at many distributary heads (none of the three distributaries discussed here have functioning downstream gauges), regulation of head discharge becomes a matter of guesswork or an "art." Accumulated experience is certainly helpful. So, too, is the presence of a readily adjustable mechanical gate, as at Mananwala head where comparative data suggest that the information gap between measured and recorded discharge is often within the range of the accepted measurement error. However, even in the absence of the latter condition, it seems certain that if gatekeepers were able to use their accumulated experience in conjunction with reliable information, variability in distributary discharge could be better controlled than being done now.

CONCLUSION

Although the research activities and results reported here are limited in their geographic scope relative to the size of Pakistan's canal irrigation environment, at least one broad, general conclusion seems inescapable. If a more productive and sustainable irrigated agriculture is a system performance objective, then the results thus far from research on distributaries in the LCC system point to the need for a more reliable, precise and disaggregated view of within-system canal performance than has so far been available. This is an important, perhaps essential, first step in developing appropriate and effective management interventions. Although a productive start has been made in this direction in a single large Punjab canal system, there remain substantial gaps in our understanding of distributary-level canal performance. An especially important gap concerns actual main system operations and their impact upon distributaries in the LCC.

There has been sufficient research progress to begin actively considering management options to improve both the equity and reliability of water distribution to farmers at the distributary level. Several initiatives to do just that in a more "action research" mode, involving irrigation agency cooperation and collaboration with IIMI Pakistan, are already underway or are being planned for implementation.

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