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Research Report

Impact Assessment of Rehabilitation Intervention in the Gal Oya Left Bank

Upali A. Amarasinghe, R. Sakthivadivel, and
Hammond Murray-Rust

International Irrigation Management Institute

Research Reports

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Summary

This report presents the results of an impact assessment of rehabilitation intervention on irrigation system performance in the Gal Oya Left Bank irrigation system in Sri Lanka. The method of analysis was based on the time series intervention analysis proposed by G. E. P. Box and G. C. Tiao. This model is used to separate the impacts of rehabilitation intervention in the presence of effects of both exogenous inputs and a dependent noise structure. Intervention impact assessment models were developed for several indicators of system performance in the Gal Oya Left Bank: irrigated area, irrigation supply per unit area, total irrigation supply, productivity per unit of irrigated land, and productivity per unit of irrigation supply. Results indicate that rehabilitation had substantial overall impacts on increasing the irrigated area and decreasing the irrigation supply per unit area. Though the impacts of rehabilitation on productivity are indirect, a large increase in productivity is also seen after rehabilitation. It was also evident that improvements in performance of these indicators in the Left Bank could not have resulted from physical or institutional improvements alone. Both physical and institutional components of rehabilitation intervention implemented simultaneously have contributed significantly to increasing the irrigated area. Institutional improvements contributed significantly in reducing the excess irrigation supply to the Left Bank.

Impact Assesment of Rehabilitation Intervention in the Gal Oya Left Bank

Upali Amarasinghe, R. Sakthivadivel, and Hammond Murray-Rust

Introduction

An irrigation system may simultaneously undergo several physical, institutional, operational, and managerial interventions. Some individual components of these interventions are quantifiable, and the impacts of them on performance indicators can be investigated using multiple regression techniques. But some components of interventions are not quantifiable. In such instances, time series intervention analysis (Box and Tiao 1975) is an extremely useful technique for impact assessment.

In recent years, various types of interventions associated under the broad rubric of rehabilitation and modernization of irrigation systems have been implemented to improve irrigation and agricultural system performance. Identification of the nature and magnitude of the impacts of these interventions could improve selection and implementation strategies when similar interventions are considered in other systems. An intervention may cause a sharp change in system performance or it may be gradual. In the event of a sharp change, the nature of change is visible in time series plots of relevant indicators of performance. In many situations, noise[1] associated with indicators is so large as to mask a visible change in performance. In some situations, exogenous factors that influence the indicators may also have undergone a simultaneous change. If the changes due to exogenous factors are not accounted for, the impacts of interventions may be overestimated or underestimated. Often, this is the case of interventions in irrigation systems.

For example, in an irrigation system rehabilitated to improve water supply to downstream areas, major changes in rainfall occurring simultaneously would affect the additional capacity of canals provided under the rehabilitation to deliver the water to the downstream areas. Unless the effect of rainfall is accounted for, the impacts of the rehabilitation would be overestimated.

Impact assessment of interventions in irrigation systems is being routinely carried out, especially in donor-funded projects. Some important impact assessments of irrigation systems are Vander Velde and Murray-Rust 1992 (canal lining and desilting), Svendsen and Vermillion 1992 and Vermillion and Garcés Restrepo 1996 (irrigation management turnover), PRC Engineering Consultants 1985 (rehabilitation of Gal Oya Left Bank), and IIMI 1995 (Kirindi Oya impact assessment studies). A weakness of most of these studies is their inability to separate the impact from the effect of noise and exogenous inputs.

This report presents the results of an impact assessment of rehabilitation interventions on irrigation system performance

[1]Random deviations from the deterministic component.

in the Left Bank of the Gal Oya irrigation system using time series intervention analysis. The irrigation system performance indicators used as dependent variables in the analysis are irrigated area, irrigation supply per unit area, total irrigation supply, productivity per unit of land, and productivity per unit of irrigation supply.

Background on the Gal Oya Left Bank System and Its Rehabilitation

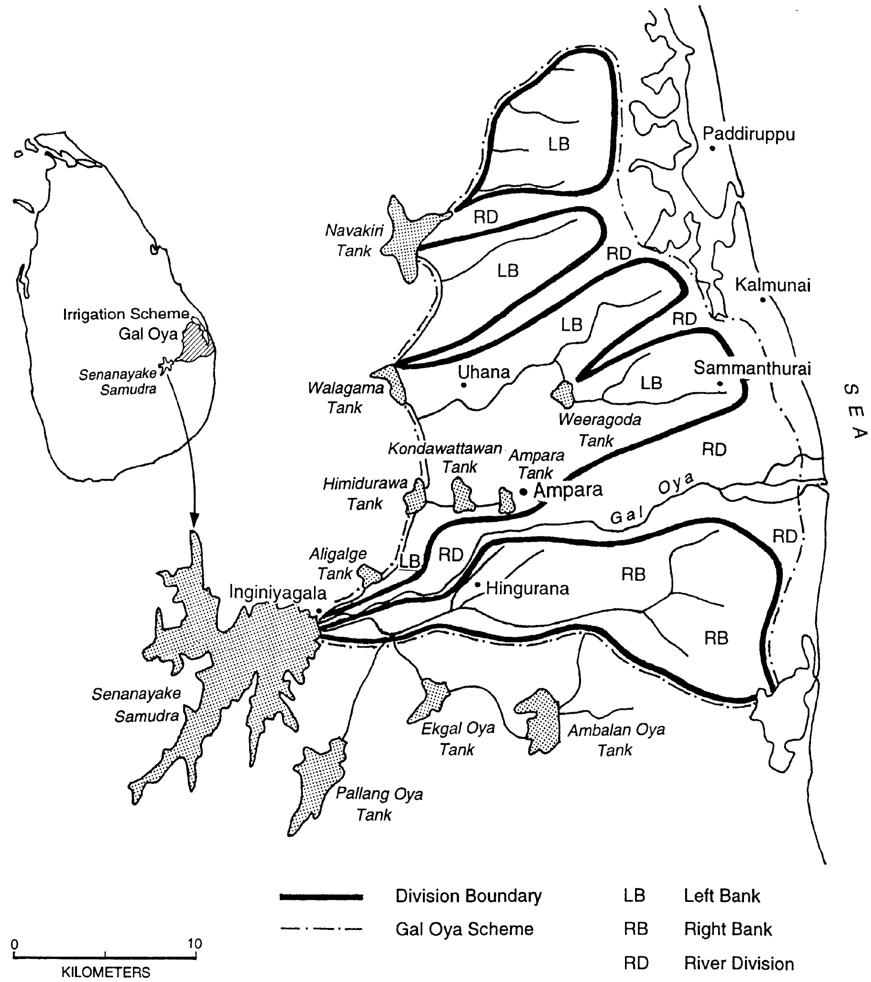
Gal Oya, a reservoir-based irrigation system, lies on the eastern coastal plain of Sri Lanka (fig. 1). Originally proposed just after Sri Lanka's independence in 1948, the main reservoir was completed in 1960, and the full irrigation system was transferred from the Gal Oya Development Board to the Irrigation Department for routine operation and maintenance. The reservoir, Senanayake Samudra, has a capacity of 979 million cubic meters. Immediately below the dam is a trifurcation that controls water deliveries into the main divisions of the system: the Right Bank (11,741 ha), the River Division (8,502 ha), and the Left Bank (16,328 ha). Its combined irrigated area makes Gal Oya the largest contiguous irrigation system in Sri Lanka.

In the River Division and Left Bank areas, rice monoculture is practiced in two distinct seasons: maha (the wet season from October to March) and yala (the dry season from April to August). Some 4,000 hectares of the Right Bank are under sugarcane cultivation. Because irrigation of sugarcane is only planned for daylight hours, at least 4,000 hectares of rice are cultivated using nighttime flow and drainage water from the sugar fields.

Until 1974, the system was run on a more or less continuous flow at or near the full supply level. However, as a result of canal deterioration, it became necessary to implement rotational irrigation in the Left Bank. In some places, the main and branch canals had doubled in width due to erosion of their banks. The virtual absence of cross-regulators meant that the system could only serve distributary channels by being operated at or near the designed water level, resulting in excess discharges into the system that could have drained the reservoir before the end of the season. In addition, most gates controlling the heads of distributary channels were broken, so that there was little functional control over irrigation water.

FIGURE 1.

The Gal Oya Irrigation Scheme.



A succession of dry years compounded the problems. Prior to the rehabilitation, the reservoir had last filled in 1964. And although there was good rainfall through the 1960s, the last time the reservoir had reached more than adequate capacity was in 1971. Subsequently there was a declining trend in reservoir storage, with a commensurate decline in the area irrigated.

By the mid-1970s, it was clear that without rehabilitation the system's performance would continue to deteriorate. Following a request from the Government of Sri Lanka, the U.S. Agency for International Development agreed to fund the rehabilitation of the Gal Oya Left Bank system. Planning for this project began in 1978, and actual field activities started in 1981.

Rehabilitation Activities

Initially, the aim of the rehabilitation project was to restore the physical capacity of the canal system, but during the planning stage, it was agreed to make a major effort to establish farmer organizations and to implement a participatory program for the operation and maintenance of the system once physical rehabilitation was completed.

The principal components of the rehabilitation were:

- *physical improvements* to main and branch canals including strengthening weakened sections and providing sufficient cross-regulators to enable the canals to be operated with continuous flow even when discharges were below maximum design discharge
- *physical improvements* to distributary and field channels that included provision of cross-regulators and construction of new field channels to eliminate direct outlets from distributary channels to individual farms wherever possible
- *installation of measuring devices* at the head of distributary channels and reestablishment of measurement capacity at key control points in the main and branch canal system
- *computerization of monitoring* to allow discharges to be measured daily while weekly adjustments are made to gates to keep discharges at or near actual field level water requirements
- *establishment of area committees* in each of the six main units of the system including representatives of all distributary channel groups, the Irrigation Department, and the Department of Agriculture to discuss and resolve local disputes over water and other inputs at monthly meetings
- *inclusion of farmer representatives in the district level committee,* who fully particite in seasonal planning meetings that determine the area to be authorized for irrigation, based on the storage in the reservoir before each season, and who help set priorities for spending maintenance funds that have been collected through the payment of irrigation service fees

TABLE 1.

Actual changes in mean levels of rainfall, reservoir storage, irrigated area, irrigation supply, and productivity from the pre-intervention period (before 1982) to the post-intervention period (1982 and later).

	Rainfall (mm)		Storage (10^6 m^3)		Irrigated area (000 ha)		Irrig. supply/ unit area (mm)		Total irrigation supply (10^6 m^3)		Land productivity[a] (t/ha)		Water productivity[a] (kg/m^3)	
	Yala	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala	Maha
Before 1982	376	1,185	434	129	10.2	13.7	2,704	1,321	279	181	2.6	2.7	0.10	0.29
1982 and later	288	1,296	569	217	14.0	16.3	1,875	793	257	129	3.9	4.0	0.21	0.56
Change (%)	-23	9	31	68	37	19	-31	-40	-8	-29	51	48	108	95

[a]Husked rice yield.

Hypotheses

Following the rehabilitation of the Gal Oya Left Bank, some performance parameters improved considerably (table 1). For example, the average irrigated area in yala and maha increased 37 percent and 19 percent, respectively, and water application rates (irrigation supply per unit area) in yala and maha decreased 31 percent and 40 percent, respectively. However, the exact reasons for these improvements have been intensely debated. Three factors are considered the primary causes:

- *institutional improvements,* particularly the role of the farmer organization
- *physical improvements* to the canal system that reestablished effective control over water deliveries at the main and branch canal levels and at the distributary channel level
- *heavy rainfall and huge increases in reservoir storage* in the 1983/84 maha season that coincided with the completion of the rehabilitation program which are shown in figures 2 and 3.

FIGURE 2.

Seasonal rainfall, Gal Oya Left Bank, yala and maha seasons, 1969-92.

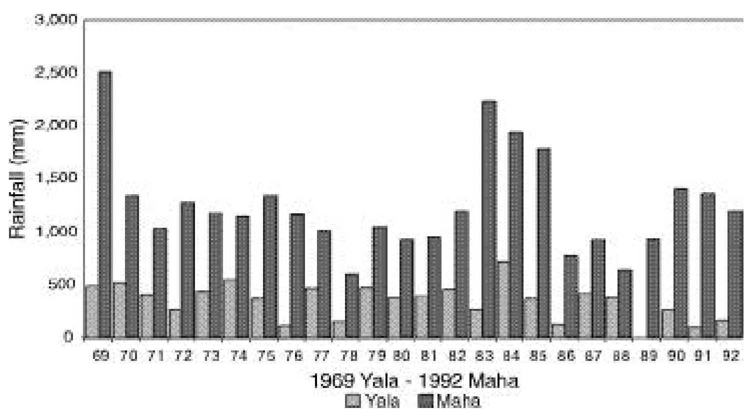
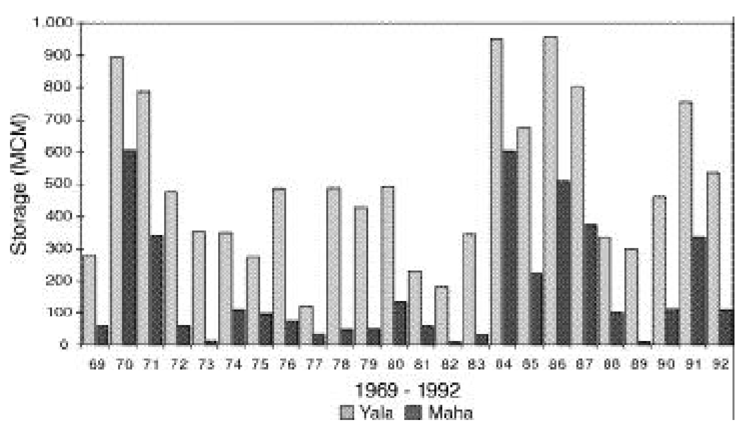


FIGURE 3.

Reservoir storage, Senanayake Samudraya, yala and maha seasons, 1969-92.



The evaluation report for the project (PRC Engineering Consultants 1985), completed shortly after the end of the rehabilitation, largely ignored increases in the reservoir storage as a factor in improved performance of the system. Other documents (Merrey and Murray-Rust 1987; Murray-Rust and Moore 1982; Uphoff 1992) have generally focused on the role of the farmer organization program.

To disaggregate the impacts of variations in exogenous factors, rehabilitation interventions, and noise components, we applied a time series intervention impact analysis. The modeling approach was used to investigate the hypotheses that rehabilitation of Gal Oya had direct impacts on:

- increasing the irrigated area
- decreasing the irrigation supply per unit area
- decreasing the total irrigation supply

In addition, the modeling approach was used to investigate the hypotheses that rehabilitation had indirect impacts leading to:

- increasing productivity per unit of land (land productivity)
- increasing productivity per unit of irrigation supply (water productivity)

Data are available for the following basic variables for 1969 yala to 1992 maha: *daily reservoir water levels* (also converted to reservoir storage), *daily rainfall* (measured at Ampara), *daily issues* (to the three divisions from the reservoir), *daily water levels* at key locations within the Left Bank, and *irrigated* area by season. Data on rice *yields* are available for every season from 1974 to 1992.

Water delivery data were provided by the Irrigation Department office at Ampara and agricultural productivity data were provided by the Ampara District Agricultural Office.

The Intervention Impact Assessment Model

The intervention impact assessment model comprises three components: exogenous factors, intervention component, and noise component. The model can be expressed as

$$y_t = X_t + I_t + N_t$$

where y_t = system performance indicator, X_t = effect of exogenous inputs (rainfall and reservoir storage), I_t = impact of interventions (institutional and physical improvements), and N_t = random noise component.

The seasonal rainfall and the reservoir storage at the beginning of the season (October 1 for maha season and April 1 for yala season) are used as exogenous inputs in the intervention impact assessment model.

Reservoir storage was assumed to be managed only within the context of an individual season. Although it is possible to manage reservoirs so that water will be deliberately conserved from one season to the next, there is no evidence that this is done at Gal Oya. Observations and interviews suggest that for yala there is no effort to carry over a specific target volume for use at the start of the following maha. In maha, reservoir storage is used as required to meet the crop water demands during periods when rainfall is inadequate. Planning for yala does not normally commence until the rains have ceased and the reservoir is close to its maximum storage for the year. As a result, it appears valid to treat reservoir storage as an exogenous variable.

The intervention component of the model consists of two parts: impact during rehabilitation (in 1982 and 1983) and impact after rehabilitation (after 1984). The overall impact of rehabilitation in the Gal Oya Left Bank was considered to be the aggregate of the impacts of two interventions: physical improvements and institutional improvements. Physical improvements relate to improvements in the main and branch canals and in the distributaries and field channels, construction of new field channels, installation of measuring devices, etc. Institutional improvements relate to all aspects of improvements in operation, maintenance, and management of the physical structures including organizing farmers and involving them in joint decision making in operational planning and maintenance of the system.

During rehabilitation, only the overall impact was modeled as the average impact of 1982 and 1983 maha and 1982 and 1983 yala, respectively. After rehabilitation, the model treats improvements in physical conditions and institutional capacity as two interventions.

The noise component is modeled using a mixed auto-regressive integrated moving average (ARIMA) model (Box and Jenkins 1970). Details of the identification of the forms of the three components for different indicators are discussed in Amarasinghe, Sakthivadivel, and Murray-Rust 1997. For example, the impact assessment model for irrigation supply per unit area can be written

$$
\begin{aligned}
\text{In}(ISUA_t) \;=\; & \omega_1 RF_t + \omega_2 STOR_t + \omega_3 P_t Y \\
& + \omega_4 P_t^{M} + (\omega_p / (1 - (\delta_P B)) P_t^{84} \\
& + (\omega_1 / (1 - (\delta_I B)) S_t^{84} \\
& + (1 / (1 - \Phi B^2)) a_t
\end{aligned}
$$

where

ISUA = irrigation supply per unit area (mm),

RF = rainfall (mm),

STOR = reservoir storage (10^6 m^3),

P_t^Y = 1 if t = 1982 and 1983 yala seasons, or 0 otherwise,

P_t^M = 1 if t = 1982 and 1983 maha seasons, or 0 otherwise,

P_t^{84} = 1 if t = 1984, or 0 otherwise,

S_t^{84} = 1 if t ò 1984, or 0 otherwise,

a_t = a mean zero constant variance normal random variable,

B = backward shift operator defined by

$B^k(Z_t) = Z_{t-k}$, k = 0, 1, 2 . . . . for any variable Z_t.

The first two terms on the right hand side of the equation represent the exogenous input component containing the effects of rainfall (RF) and reservoir storage (STOR), and ω_1 and ω_2 are the respective coefficients. The third and fourth terms, P_t^Y and P_t^M, are the overall impacts of rehabilitation during the rehabilitation period (1982 and 1983). The coefficients ω_3 and ω_4 are the magnitudes of the average impacts in yala and maha seasons, respectively. The fifth term, P_t^{84}, is the impact of physical improvements after the rehabilitation period (from 1984). The coefficient ω_P is the magnitude of the impact in the initial time period after rehabilitation, and δ_P is the rate of change in the impact thereafter. The sixth term, S_t^{84}, is the impact of institutional improvements after the rehabilitation period. The coefficient ω_I is the magnitude of the impact in the initial time period after rehabilitation, and δ_I is the rate of change thereafter. The last term is the ARIMA noise component and Φ is the seasonal auto-regressive coefficient. The coefficients ω_1, ω_2, ω_3, ω_4, ω_P, ω_I, δ_P, δ_I, and Φ are estimated using the maximum likelihood method.

Similar expressions for other system performance indicators have been developed. The forms of the exogenous inputs component and of the intervention component in the models for the two indicators—irrigated area and total irrigation supply—are the same as those for irrigation supply per unit area, except for the institutional improvement component of the total irrigation supply where it was assumed that the impact was a step input, i.e., the rate of change parameter δ_I is zero. This assumption was made to eliminate the instability of the model for total irrigation supply due to over-parameterization. The noise components of both indicators are different from that in the above model.

For the productivity indicators, the form of the exogenous inputs component of the model remains unchanged. Only the over-

TABLE 2.
Maximum likelihood estimates of coefficients of impact assessment models (*t* values in parentheses).

Variable		Irrigated area[a] (ha)	Irrigation supply/area[a] (mm)	Total irrigation supply[a] (000 m^3)	Land productivity[b] (t/ha)	Water productivity[b] (kg/m^3)
Exogenous component						
RF		0.000002 (0.05)	-0.00034 (-3.36*)	-0.00018 (-2.20*)	0.00010 (1.04)	0.00023 (6.81*)
STOR		0.000310 (4.47*)	0.0006 (3.36*)	0.00104 (5.42*)	-0.00003 (-0.13)	-0.00013 (-1.64)
Intervention component						
P_t^Y		-0.139 (-1.52)	-0.050 (-0.24)	-0.331 (-1.72)	1.000 (4.48*)	0.072 (1.13)
P_t^M		0.202 (2.26*)	-0.691 (-3.36*)	-0.501 (-2.53*)	0.799 (3.35*)	0.386 (5.13*)
P_t^{84}	magnitude	0.230 (2.26*)	0.179 (0.55)	0.078 (0.96)	-	-
	rate of change	-0.987 (-17.38*)	0.778 (1.30)	-0.996 (-9.63*)	-	-
S_t^{84}	magnitude	0.321 (2.33*)	-0.767 (-2.84*)	-0.248 (-1.49)	1.219 (4.52*)	0.045 (1.74)
	rate of change	-0.040 (-0.13)	-0.553 (-1.47)	-	0.015 (0.08)	0.784 (5.49*)
Noise component[c]						
Φ_1		0.263 (2.44*)	0.709 (6.66*)	-	-0.473 (-2.59*)	-
Φ_2		0.723 (6.78*)	-	-	-	-
ϕ_1		-	-	0.791 (5.08*)	-	-
ϕ_2		-	-	0.351 (1.40)	-	-
θ		-	-	-	-0.619 (-3.53*)	0.513 (3.45*)
R_2		0.86	0.86	0.80	0.91	0.87

*Significant at the 0.05 level.

[a] Values expressed as natural logarithms.

[b] Rice yield.

[c] F $_1$ and F $_2$, are the seasonal auto-regressive parameters; f $_1$ and f $_2$, are the nonseasonal auto-regressive parameters; q is a nonseasonal moving average parameter.

all impacts—the impacts of physical and institutional improvements—during and after rehabilitation period are considered for the intervention component. The form of the noise component also differs from those found for the other indicators.

The estimated coefficients for all indicators and their statistical significance are shown in table 2.

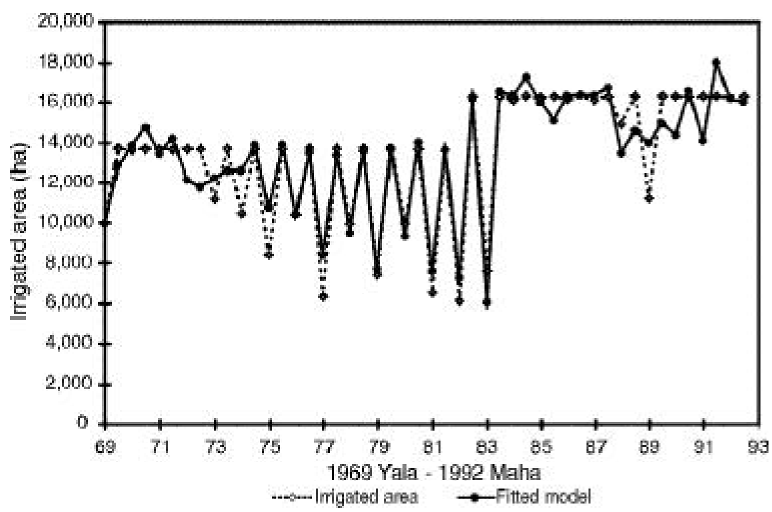
Results from the Impact Assessment Analysis

Changes in Irrigated Area

The fitted impact assessment model (fig. 4) explains a large proportion of the variation about the average irrigated area ($R^2 = 0.86$, see table 2). As expected, initial reservoir storage (STOR) was significant in explaining seasonal variation in irrigated area, as this is the key factor considered in the seasonal decisions on irrigation plans. It is well known that the storage in the reservoir before the season is the dominant factor in determining the area to be irrigated in Gal Oya. Rainfall (RF) was not significantly related, as it was not used in the decision process.

During the rehabilitation period, on average, there was no significant overall impact in yala (P_t^Y), but there was a significant positive impact in maha (P_t^M). After rehabilitation, both the magnitude of the impact due to physical improvements (P_t^{84}) at the initial time period and the rate of change thereafter are significant in explaining the

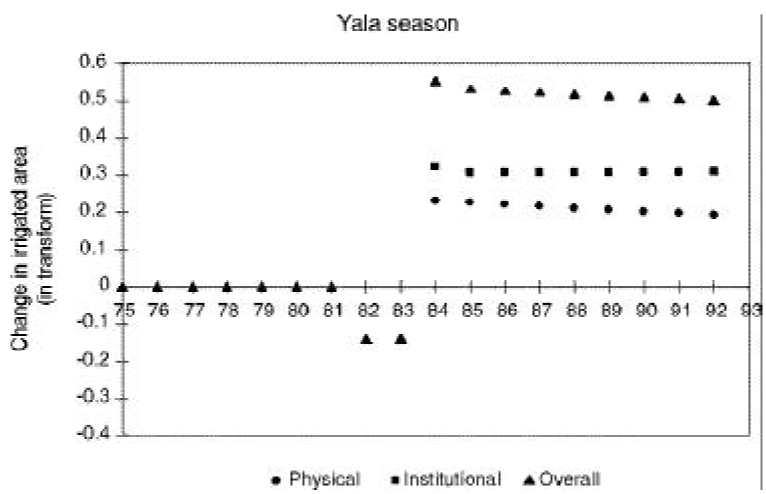
FIGURE 4.
Irrigated area, Gal Oya Left Bank yala and maha seasons, 1969-92.

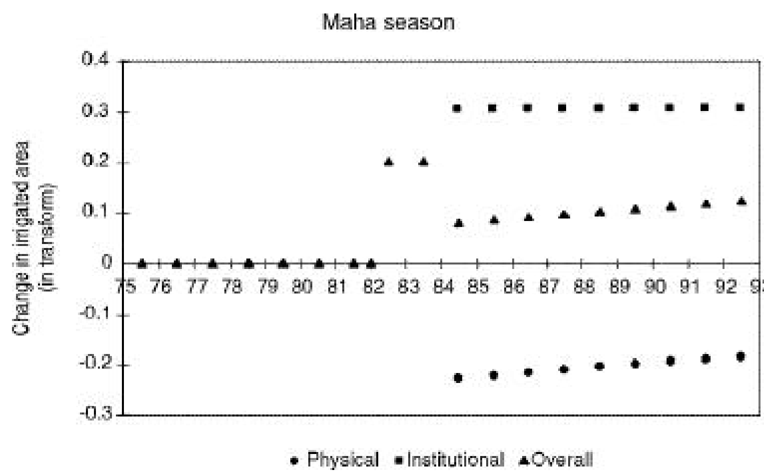


variations in irrigated area. In the institutional improvement component (S_t^{84}), though the magnitude of the impact at the initial time period is statistically significant, the rate of change is not.

The nature of the impacts due to physical and institutional improvements and the overall impact of rehabilitation for the two seasons are shown in figure 5. The absolute rate of change in the physical improvements component (0.987) is large and close to 1.

FIGURE 5.
Impact of rehabilitation (1981-1984) on irrigated area.





This shows that the impact on irrigated area was sustained over the post-rehabilitation period. The rate of change in the institutional component (-0.04) is very small, which indicates that the institutional improvements had a constant step impact on irrigated area. The overall impacts of rehabilitation on irrigated area in both seasons are positive, and the impacts are shown to be sustained in the post-rehabilitation period.

The contributions from different sources—changes in rainfall and reservoir storage—and interventions for the change in irrigated area (expressed as natural logarithms) from the period before intervention (1969-81) to the period during and after rehabilitation (1982-92) are given in absolute terms and also as a percentage of the total change (table 3). Though statistically significant in the model, reservoir storage would not have contributed to the change in irrigated area if the difference in the average reservoir storage levels were not appreciably different from zero. However, increase in average reservoir storage levels (primarily due to very high storage levels in the 2 years immediately after rehabilitation) appears to have made a small contribution (10%) to the expansion in average irrigated area (table 3). This contribution would have been higher if the average changes were computed for a shorter period before and after rehabilitation.

In maha, physical improvements had a negative effect on the total change in irrigated area, but institutional improvements made a large positive contribution (table 3). Taken together, physical and institutional improvements have contributed substantially to increasing the irrigated area. In yala, both physical and institutional improvements made a large contribution to increasing the irrigated area. It is logical to state that the physical improvements of the system, along with institutional capacity improvements, make it possible to send a greater and more reliable supply to the tail-end area farmers, the main beneficiaries in terms of area increases observed after rehabilitation, and to sustain this supply thereafter.

Institutional improvements were the major contributor to increasing maha irrigated area (table 3). In fact, the contribution from institutional improvements was large enough to more than offset the negative impacts of physical improvements on maha irrigated area. A reason for the negative impact of physical improvements may be the

TABLE 3.
Contributions (expressed as natural logarithms) from different sources to changes in irrigated area.

Source	Yala Contribution (ha)	Yala Share (%)	Maha Contribution (ha)	Maha Share (%)
Rainfall	-0.0002	0	0.0002	0
Reservoir storage	0.042	10	0.027	19
Overall rehabilitation (in 1982 and 1983)	-0.025	-6	0.037	25
Physical improvements (from 1984)	0.171	39	-0.169	-115
Institutional improvements (from 1984)	0.252	57	0.251	172
Total	0.440	100	0.146	100

high rainfall during the 1984 and 1985 maha seasons, which could have impeded the fuller utilization of the renovated main and branch canals.

The estimated average increase in irrigated area was 55 percent (exp 0.440 - 1) in the yala season and 16 percent (exp 0.146 - 1) in the maha season. These estimates are fairly satisfactory compared with the observed increases of 37 percent in yala and 19 percent in maha.

Changes in Irrigation Supply Per Unit Area

The fitted model (fig. 6) explains a substantial proportion of the variations about the average irrigation supply per unit area (water application rates) (R2 = 0.86, see table 2). Effects of both exogenous variables—rainfall and initial reservoir storage—were significant in explaining the variations in water application rates (table 2). This shows there was a positive response (reduction of irrigation supply) to the rainfall received during the season. When the initial reservoir storage was high, the irrigation managers tended to supply more water, perhaps more than what was required in the field, and when the storage was low they tended to supply less water.

The average impact of rehabilitation on maha water application rates during the rehabilitation period was statistically significant. After rehabilitation, the impact of physical improvements on water application rates was not significant, but the impact of institutional improvements was statistically significant (table 2). Negligible increases in water application rates due to physical improvements after 1984 (fig. 7) may be the result of better conveyance capacity coupled with heavy rainfall received in the three maha seasons after 1984.

Table 4 shows contributions from different sources for the changes in irrigation supply per unit area. Estimated net reductions of the irrigation supply per unit area

FIGURE 6.
Irrigation supply per unit area, Gal Oya Left Bank, yala and maha seasons, 1969-92.

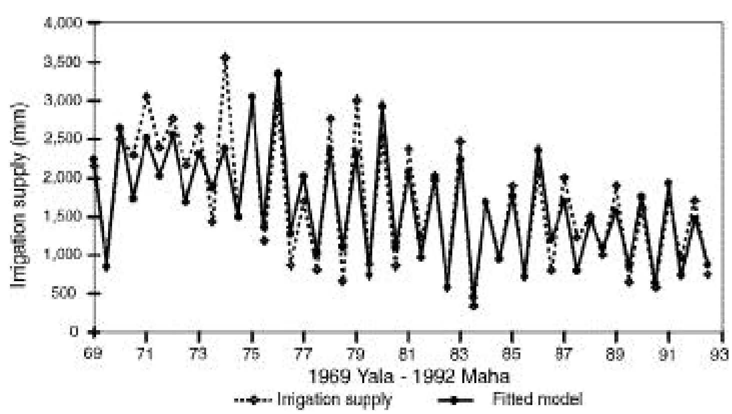


FIGURE 7.

Impact of rehabilitation (1981-84) on irrigation supply per unit area.

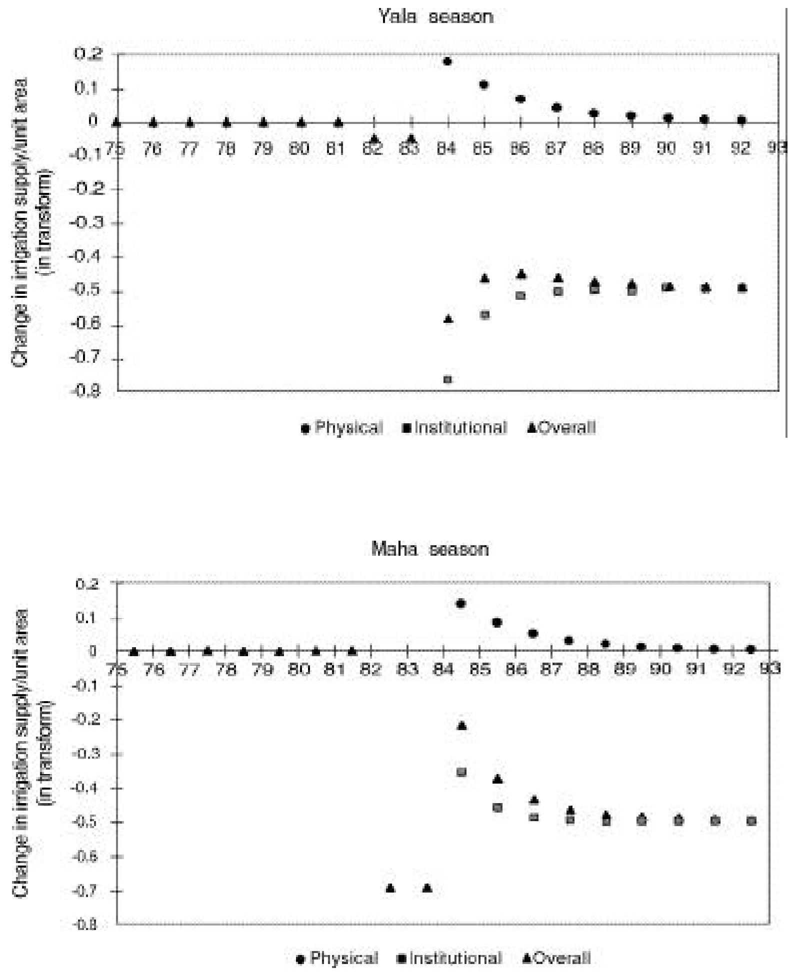


TABLE 4.

Contributions (expressed as natural logarithms) from different sources to changes in irrigation supply per unit area.

	Yala		Maha	
Source	Contribution (mm)	Share (%)	Contribution (mm)	Share (%)
Rainfall	0.030	-10	-0.037	8
Reservoir storage	0.080	-26	0.052	-11
Overall rehabilitation (in 1982 and 1983)	-0.009	3	-0.126	27
Physical improvements (from 1984)	0.041	-14	0.031	-7
Institutional improvements (from 1984)	0.443	147	0.391	83
Total	0.301	100	0.470	100

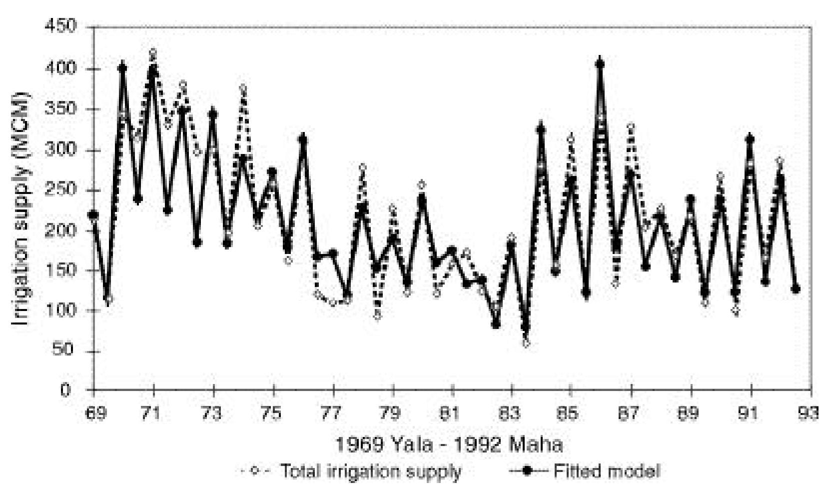
from the pre-intervention period are 26 percent (1 - exp(-0.301)) in yala and 37 percent (1 - exp(-0.470)) in maha. These are fairly consistent with the actual reductions of mean levels, 31 percent in yala and 40 percent in maha.

Institutional improvements after rehabilitation were shown to have a considerable impact in reducing the water application rates in both seasons after 1984, and this reduction was large enough to offset the slight increases in water application rates due to physical improvements and increase in the reservoir storage (table 4). In yala, institutional improvements played a major role in reducing water application rates, more than overcoming the negative effects of reduction of average rainfall, increased average reservoir storage levels, and physical improvements. In maha, increase in average rainfall, positive overall impacts during rehabilitation, and the impact of institutional improvements after rehabilitation all contributed to reducing the water application rates.

Changes in Total Irrigation Supply

The fitted model (fig. 8) explains a substantial proportion of variations about the average total irrigation supply (R2 = 0.80, see table 2). Effects of the changes in rainfall and reservoir storage explain most of the variations in total irrigation supply. The total irrigation supply has a significant negative relationship with rainfall (table 2). This suggests that water releases are curtailed or stopped when there is a substantial amount of water from rainfall. Reservoir storage has a significant positive relationship with total irrigation supply. This shows that there is a tendency to release more water when there is higher reservoir storage at the be-

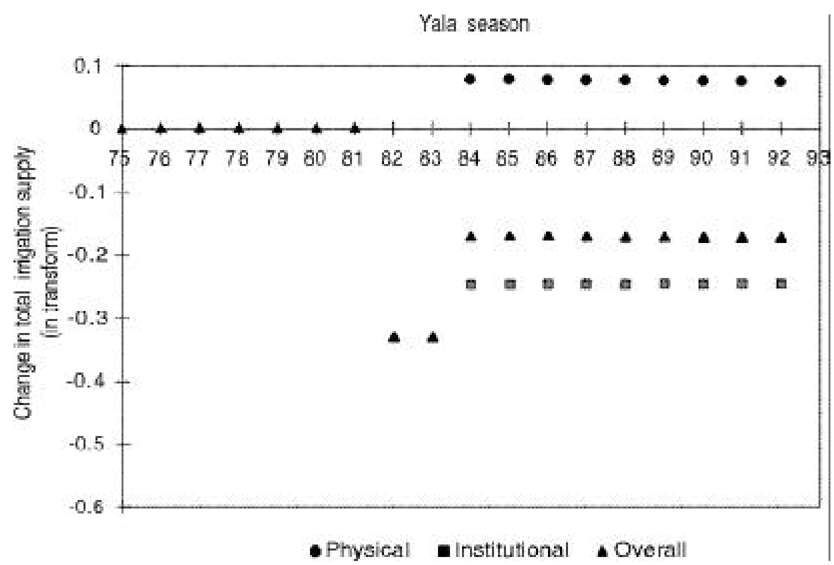
FIGURE 8.
Total irrigation supply, Gal Oya Left Bank.

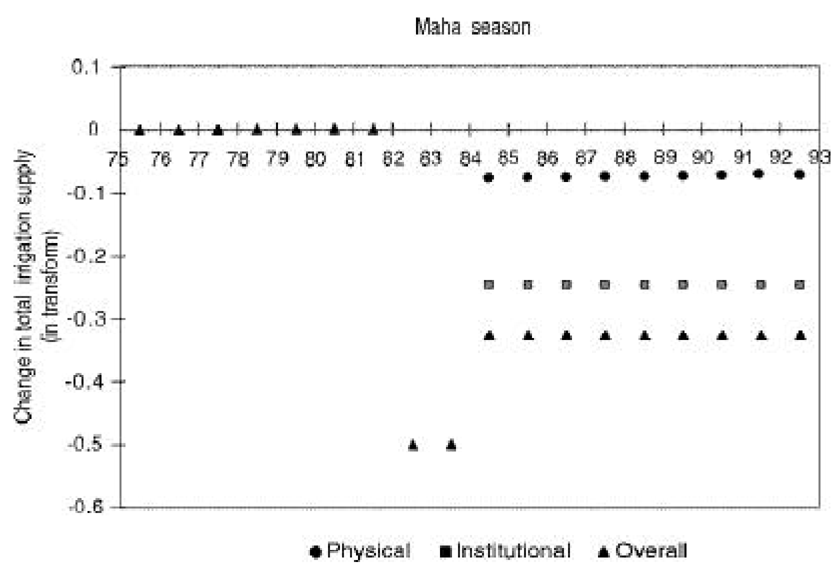


ginning of the season and less when there is low reservoir storage.

The average overall impact of rehabilitation on 1982 and 1983 maha total irrigation supply is statistically significant. However, the overall impact in yala during rehabilitation and the impacts of physical and institutional interventions on total irrigation supply after rehabilitation are not statistically significant (table 2). The nature of the impacts due to physical and institutional improvements (fig. 9) shows that, though the magnitude is not large, rehabilitation has contributed to decreasing the total irrigation

FIGURE 9.
Impact of rehabilitation (1981-84) on total irrigation supply.





supply in both seasons even though the irrigated area was increased in both seasons. The reason for the negligible reduction in total irrigation supply may be that the increased irrigated area has consumed part of the savings in water application after rehabilitation. Contributions from different sources for the changes in total irrigation supply are given in table 5.

Estimated reductions in mean level are 5 percent (1 - exp(-0.045)) in yala and 25 percent (1 - exp(-0.284)) in maha. These values are consistent with observed reductions of 8 percent and 29 percent in the two seasons. The high negative contribution of reservoir storage in yala suggests that without rehabilitation, the total irrigation supply of the post-intervention period would have increased due to the higher average reservoir storage at the beginning of the season. In maha, the negative effect of the higher reservoir storage in the post-intervention period is low and was offset by the positive impacts of physical and institutional improvements.

Changes in Productivity

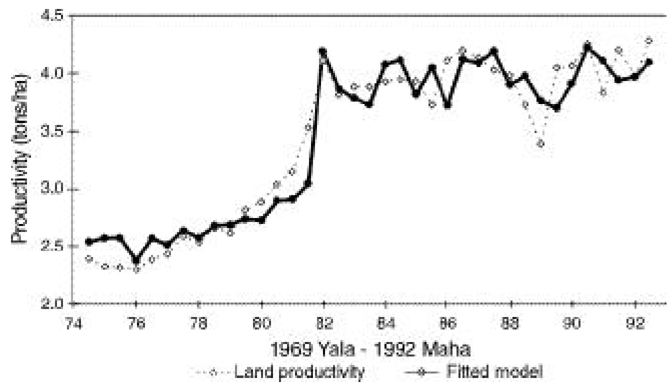
The observed average productivity per unit of irrigated land (land productivity) in the post-intervention period increased by 51 percent in yala and by 48 percent in maha. The increments in the productivity per unit of irrigation supply (water productivity) for the two seasons were 108 percent and 95 percent (table 1). Such increases in productivity after rehabilitation may be due to a combination of factors such as gradual increase in the use of high yielding varieties, better input applications, and better water management. Rehabilitation may have had a direct impact on the changes in some of these factors and, in general, these changes have a direct impact on the changes in productivity. Therefore, rehabilitation may only have an indirect impact on the changes in productivity, especially land productivity.

Information on area under high yielding varieties, on inputs, etc., was not available for the present analysis, and productivity data were available only from 1974. Therefore, the effects of the two exogenous variables (rainfall and reservoir storage) and of the overall changes (due to other sources after the rehabilitation period) on the changes in productivity were investigated.

TABLE 5.
Contributions (expressed as natural logarithms) from different sources to changes in total irrigation supply.

	Yala		Maha	
	Contribution	Share	Contribution	Share
Source	(000m^3)	(%)	(000m^3)	(%)
Rainfall	0.016	-35	-0.020	7
Reservoir storage	0.140	-313	0.092	-32
Overall rehabilitation (in 1982 and 1983)	-0.060	134	-0.091	32
Physical improvements (from 1984)	0.062	-138	0.062	22
Institutional improvements (from 1984)	0.203	452	0.203	71
Total	0.045	100	0.284	100

FIGURE 10.
Productivity per unit irrigated area, Gal Oya Left Bank, maha and yala seasons, 1975-92.



Productivity per unit of irrigated area

The fitted model (table 2 and fig. 10) explains a high percentage of the variations about the average land productivity. However, neither rainfall nor reservoir storage is statistically significant in explaining the variations. The average land productivity of yala and maha in 1982 and 1983 is significantly different from that in other years. Also there was a significant positive change after 1984 due to rehabilitation and exogenous factors except rainfall and storage. The estimated average land productivity increments due to sources other than rainfall and reservoir storage are 1.18 t / ha in yala and 1.14 t / ha in maha (table 6).

Part of the production increase after rehabilitation may be due to the direct impact of better water management, which in itself is a direct impact of rehabilitation. Also, better inputs such as fertilizer, pesticide, and herbicide applications, which may or may not be a direct impact from better water distribution, may have contributed to production increases. Therefore, it can be concluded only that part of the land productivity increases after 1982 were due to indirect impacts of rehabilitation intervention.

Estimated changes in land productivity from the pre- to the post-rehabilitation period in yala and maha, respectively, are 1.17 t / ha and 1.16 t / ha, which compare favorably with the observed changes of 1.34 t / ha and 1.30 t / ha for the two seasons.

TABLE 6.
Contributions from different sources to change in land productivity (rice yield).

	Yala		Maha	
Source	Contribution (t/ha)	Share (%)	Contribution (t/ha)	Share (%)
Rainfall	0.004	-0	-0.028	2
Reservoir storage	0.007	-1	0.004	0
Other sources	1.18	100	1.14	98
Total	1.17	100	1.16	100

Productivity per unit of irrigation supply

The fitted model (fig. 11) explains a substantial proportion of the variations about the average water productivity ($R^2 = 0.87$, see table 2). Rainfall had a significant positive effect in explaining water productivity variations. This may be because rainfall had a significant positive effect on irrigation supply per unit area. Therefore, it can be expected that higher rainfall, and hence lower irrigation supply would result in higher water productivity, and vice versa. Reservoir storage, though not significant, has a negative relationship with water productivity. This is because higher reservoir storage was shown to have a negative effect on irrigation supply. Therefore, higher reservoir storage, and hence higher irrigation supply, would result in lower water productivity.

In maha 1982 and 1983, the average water productivity was significantly higher than in other years. Also, the other sources, including rehabilitation, had a significant gradual impact on water productivity after 1984. The contributions of different sources to the change in water productivity are given in table 7.

Decreased average rainfall and increased reservoir storage in yala have a negative contribution to the change in water productivity. However, the sources other than exogenous inputs, including rehabilitation, were able to offset the negative impact and achieve substantial gains in water productivity in yala. In maha, higher average rainfall also had a substantial impact on increasing water productivity levels.

FIGURE 11.

Productivity per unit irrigation supply, Gal Oya Left Bank, maha and yala seasons, 1975-92.

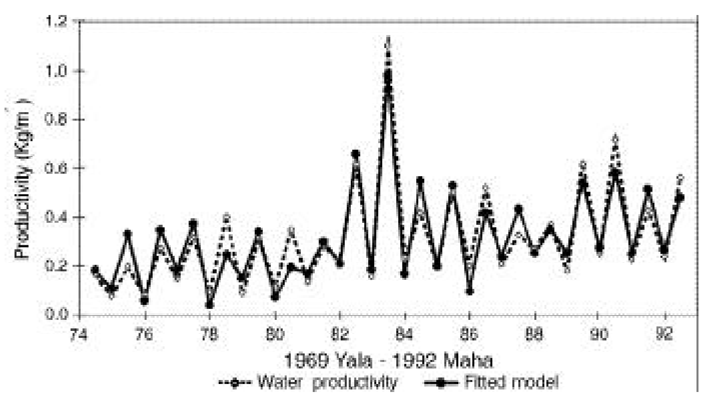


TABLE 7.

Contributions from different sources to change in water productivity: Contributions from different sources.

	Yala		Maha	
Source	Contribution (kg/m³)	Share (%)	Contribution (kg/m³)	Share (%)
Rainfall	-0.008	-8	0.066	25
Reservoir storage	-0.027	-24	-0.018	-7
Other sources	0.146	132	0.211	82
Total	0.111	100	0.259	100

Comparison with Other Studies and Observations

In this section, the results discussed in the previous section are compared with some other studies and observations and experience in the field. In the Gal Oya Left Bank there are comprehensive studies of conditions before rehabilitation (Farmer 1957; Murray-Rust 1983; Murray-Rust and Moore 1982), during rehabilitation (Uphoff 1992), and after rehabilitation (Merrey and Murray-Rust 1987; PRC Engineering Consultants 1985).

Evaluation of the Importance of Exogenous Variables

Comparison of the results with observations experienced in the field shows that the model correctly assigns the impact of the two main exogenous variables—rainfall during the season and reservoir storage at the beginning of the season—in influencing the changes in different impact assessment indicators.

Rainfall

Rainfall is not a factor in the process of determining how much land is to be allocated for irrigation in the Gal Oya Left Bank. For maha, it is assumed that there will be sufficient rainfall to permit all areas to be irrigated and that in the event of dry spells enough storage will be available in the reservoir to compensate for lack of rainfall. For yala, rainfall is never adequate for rice cultivation, therefore all planning is based on observed storage in the reservoir before the season begins (possibly including some allowance for modest inflow into the reservoir). In the analysis of planning decisions made prior to rehabilitation, no evidence was found that probable rainfall was included in planning decisions, other than a hope for rain when the reservoir storage was at critically low levels before the start of yala (Murray-Rust and Moore 1982; Murray-Rust 1983). Similarly, the model does not find rainfall to be a major consideration in the planning process, i.e., when determining the area to be irrigated in a season.

There is well-documented evidence (Murray-Rust 1983) of operational responses to rainfall during most seasons. This is especially true in maha when rainfall is often far in excess of crop water requirements, and the entire system is shut down for extended periods.

Rainfall is significant in explaining the variations in irrigation supply per unit area and also the variations in total volume of water used.

Reservoir storage

The model correctly identifies that reservoir storage contributes significantly to irrigated area, volume used per unit area, and total volume issued. It would be difficult to underestimate the importance of reservoir storage in all aspects of decision making at Gal Oya. The Irrigation Department is always well informed about storage, as, increasingly, are farmers and farmer leaders since institutional changes were implemented.

Reservoir storage is obviously a key determinant of the area to be irrigated and of the total volume of water issued to the system. It is less obvious why there should be a strong and significant relationship between storage and irrigation supply (water use) per unit area. If there is a constant anticipated water use per season (duty) for each crop type, then reservoir storage would not influence the value of "duty." In practice, however, storage does influence the rate of water application. In years when the reservoir has relatively low storage in either maha or yala, efforts are made to conserve this water by minimizing the duration and volume of irrigation releases. As a result, in years of low storage, farmers reduce rates of water application because of system level reductions in the total amount of water available for irrigation. Such management practices are unpopular and have caused conflicts between farmers and the Irrigation Department. More water appears to be issued per unit area from the reservoir in years of higher storage to avoid such friction. The model, therefore, is completely consistent in determining that reservoir storage has a strong positive correlation with water use per unit area as well as on total water use.

Evaluation of the Impacts of Rehabilitation

Impact assessment of the rehabilitation of the Gal Oya Left Bank was divided into the average overall impact in 1982 and 1983 yala and maha, i.e., during rehabilitation, and the disaggregated impact from 1984 onwards, i.e., after rehabilitation.

Impact during rehabilitation

Except for land productivity, the models do not find significant improvements in any of the indicators in yala during rehabilitation. However, there are significant improvements in the average values of indicators in the two maha seasons. This may be because the resource, i.e., the water in the reservoir at the beginning of yala seasons, was very low (very high use of water per unit area in the maha seasons), and there was little irrigation in the yala seasons.

Impact after rehabilitation

The overall impact from 1984 onward was considered to be an aggregate of impacts due to physical and institutional improvements.

Benefits from physical improvements. From 1984 onward, the model indicates a significant impact of physical improvements on the area irrigated (table 2). This is to be expected, given the completion of all of the main canal work, including provision of cross-regulators and the reestablishment of hydraulically efficient cross-sections right down to the tail of the distribution system.

These conclusions are consistent with the field observations prior to rehabilitation. The deteriorated canals in the lower portions of the Sammanturai and Mandur units in the Left Bank made it almost impossible to supply water into the tail-end distributary and field channels (some channels had disappeared completely and farmers were forced to rely on rainfall to grow rice in the maha season). Water could be delivered to the tail areas only if the main canal system was run at dangerously high levels for an extended period. On one occasion in 1981, all head-end distributary channels were shut for 2 to 3 days to allow water to pass to the tail, but even then the tail-end discharges were far below design values (Murray-Rust 1983).

The results from the model (table 2) also indicate that improved hydraulic conditions have led to greater (though statistically insignificant) use of irrigation water per unit area and an increase in total irrigation supply into the system in yala. These results are consistent with conventional wisdom: if canal capacity were improved then, other things being equal, farmers at the head end would have opportunities to take a larger share of water per unit area, unless there are social or economic pressures that encourage water savings.

Benefits from institutional improvements. The model (table 2) finds that institutional changes had a significant impact on increasing the irrigated area and decreasing the water use per unit area. A primary reason for these benefits is the establishment of a transparent and democratic process of consultation that allows users and managers to fully discuss how much land to authorize for irrigation and which areas should benefit. A rational approach that is generally more egalitarian has replaced political and other ad-hoc methods of planning, though in both 1988 and 1989 when water was deemed insufficient to irrigate the entire Left Bank command area, only the tail-end areas were denied water.

A second reason is that farmer organizations, especially in the head end, have been encouraged to take only as much water as they require, rather than taking too much, as they did before 1983, and letting the surplus flow into the drains. These decreases in water use per unit area allowed more water to be delivered to the tail end of the system, and thus increased the total irrigated area. The model identifies this as an important trend that overrides the potential for head-end farmers to take more water as a result of physical improvements.

The institutional interventions also appear to lead to lower, though not significantly, total water used in both seasons, with maha savings being higher.

Conclusion

Impact assessment analysis in the Gal Oya Left Bank shows that with proper impact specification and model identification, the nature and magnitude of the impacts of different interventions can be separated from the effects of simultaneous changes in dominant exogenous factors. Even where the impacts are not statistically significant, the models identify trends in performance parameters that are entirely consistent with both conventional wisdom and observations made in Gal Oya before, during, and after rehabilitation.

Assessment of different sources (rainfall, reservoir storage, physical improvements, institutional improvements) show that some have contributed positively and some have contributed negatively to the changes in indicators (irrigated area, irrigation supply, and land and water productivity). However, the net contributions are positive, and all indicators show improvement in performance after rehabilitation.

The impact assessment models indicate very strongly that improvements in performance in all indicators could not be obtained through either physical or institutional interventions in isolation. Physical improvements significantly helped expand the irrigated area, but at the same time helped increase the water use per unit area and total volume released, which were already in excess of the requirements. The institutional improvements helped offset the excess releases that were possible due to physical improvements.

Institutional interventions alone might not have solved the problems that existed in the Gal Oya Left Bank. Prior to rehabilitation, the canal conditions were poor, and there was an almost complete absence of operable control structures. While institutional efforts to reduce water use per unit area might have been successful, the lack of suitable conveyance capacity at the tail end would have been a severe constraint to achieving any significant increase in irrigated area.

The impact assessment shows that there were significant water savings due to rehabilitation interventions and a significant increase in irrigated area in the Gal Oya Left Bank. The apparent small contribution of the changes in reservoir storage to the improvements in irrigated area (10% in yala and 19% in maha) is a result of calculating these contributions by taking the difference between the average reservoir storage for 13 years before 1982 and that for 11 years afterward. This gives the long-term impact of the changes in reservoir storage on increasing the irrigated area. If the differences were calculated for a few years before and after 1982, the contribution of reservoir storage changes to the changes in irrigated area would have been much higher. This would give a short-term impact for the changes in irrigated area.

There were large increases in land and water productivity. Since the impacts of rehabilitation on productivity indicators are indirect and information on other variables such as input applications was not available, quantification of rehabilitation impacts on productivity, especially land productivity, was not possible.

Although the models appear to accurately describe the impacts and trends of rehabilitation interventions in Gal Oya, it may require more testing on similar data sets before the utility of the model can be judged to be fully successful.

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