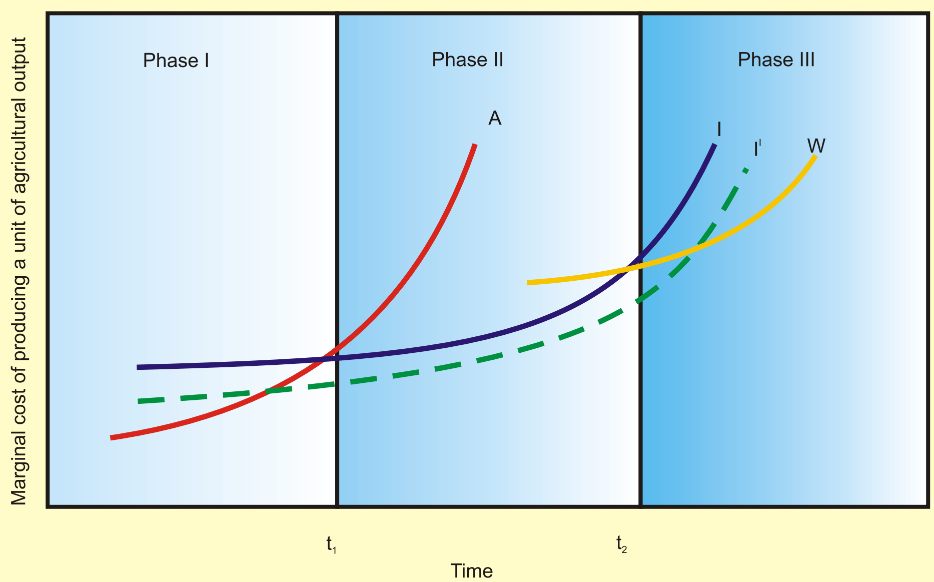
RESEARCH REPORT

62

Irrigation Sector in Sri Lanka

Recent Investment Trends and the Development Path Ahead

M. Kikuchi, R. Barker, P. Weligamage and M. Samad



IWMI
International Water Management Institute

FUTURE HARVEST
IWMI is a Future Harvest Center supported by the CGIAR

Research Reports

IWMI's mission is to improve water and land resources management for food, livelihoods and nature. In serving this mission, IWMI concentrates on the integration of policies, technologies and management systems to achieve workable solutions to real problems—practical, relevant results in the field of irrigation and water and land resources.

The publications in this series cover a wide range of subjects—from computer modeling to experience with water user associations—and vary in content from directly applicable research to more basic studies, on which applied work ultimately depends. Some research reports are narrowly focused, analytical and detailed empirical studies; others are wide-ranging and synthetic overviews of generic problems.

Although most of the reports are published by IWMI staff and their collaborators, we welcome contributions from others. Each report is reviewed internally by IWMI's own staff and Fellows, and by external reviewers. The reports are published and distributed both in hard copy and electronically (www.iwmi.org) and where possible all data and analyses will be available as separate downloadable files. Reports may be copied freely and cited with due acknowledgment.

Research Report 62

Irrigation Sector in Sri Lanka: Recent Investment Trends and the Development Path Ahead

M. Kikuchi, R. Barker, P. Weligamage and M. Samad

International Water Management Institute
P O Box 2075, Colombo, Sri Lanka

IWMI receives its principal funding from 58 governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR). Support is also given by the Governments of Ghana, Pakistan, South Africa, Sri Lanka, and Thailand.

This research was made possible through generous support from the Ford Foundation, New Delhi, SIDA (Swedish International Development Agency) and the Dutch Government.

The authors: M. Kikuchi is an International Water Management Institute (IWMI) Fellow and Professor of Agricultural Economics, Chiba University, Japan. R. Barker is a Principal Researcher, P. Weligamage is a Senior Research Officer and M. Samad is a Senior Researcher and the leader of the global theme on Water Resource Institutions and Policies, all of IWMI, Colombo, Sri Lanka.

The authors gratefully acknowledge valuable comments by Doug Merry, Thushaar Shah, Intizar Hussain, T. Jogaratnam and Gil Levine.

Kikuchi, M. ; R. Barker; P. Weligamage; and M. Samad. 2002. *Irrigation sector in Sri Lanka: Recent investment trends and the development path ahead*. Research Report 62. Colombo, Sri Lanka: International Water Management Institute.

/ irrigated farming / public investment / tube wells / pumps / rehabilitation / institutional aspects / groundwater / surface water / irrigation systems / farmer participation / river basins / pollution / sustainability / rural development / crops / agricultural development / peasants / rice / paddy cultivation / data processing / land development / infrastructure / technology / income / sprinkler irrigation / reservoirs / water delivery / water users / private investments / cropping systems / Sri Lanka /

ISBN: 92-9090-501-8

ISSN 1026-0862

Please send inquiries and comments to: *iwmi-research-news@cgiar.org*

Contents

Summary

The total investment in the irrigation sector of Sri Lanka, during the period of a decade and a half from the early 1980s to the mid-1990s, declined drastically to one seventh of its peak level in the early 1980s due a drop in public irrigation investments. Of the three types of public investment, new irrigation construction recorded the sharpest decline. Although the percentage for rehabilitation in the total irrigation investment increased, its absolute amount declined from the mid-1980s to the mid-1990s. The operation and maintenance (O&M) expenditure remained stagnant in the last two decades, and has declined since the mid-1980s. For the total irrigated area, which increased by 10 percent (50,000 ha) during this period, O&M expenditure per hectare declined considerably.

The total irrigation investment in the last half decade, showed a slight upward trend from its rock bottom level in the early 1990s. However, the relative composition of investment was entirely different from what it was before the early 1990s. Investment on rehabilitation increased and constituted the largest share in the total irrigation investment for the first time while investment in new irrigation construction continued to shrink.

Also remarkable is the rapid increase in private irrigation investment. The investment on agro-wells and irrigation pumps by farmers was negligible until the end of the 1980s, but increased rapidly in the 1990s, exceeding the O&M expenditure for the entire major irrigation schemes by a wide margin.

The rapid decline in new irrigation construction, which resulted from the drastic decline in its profitability and its sharply rising cost, in real terms, was a major factor choking off any incentive for new investment. The low rice price since the collapse of the commodity boom in the mid-1980s discouraged the government and international donor agencies from investing in new irrigation construction. Though very drastic, reduction in new construction investment is what can be expected at the present stage of development in irrigated agriculture.

The end of the construction phase signaled the beginning of the management phase with high profitability for major rehabilitation and water management improvement projects in the domain of public irrigation investment in Sri Lanka. But, the economic performance of some such projects was far less than expected, suggesting that project design and implementation with due attention to software and institutional focus are a prerequisite for the realization of their economic potential. A rough estimation of the required rehabilitation investment indicates that there was severe under-investment in the early 1990s. In spite of the high rate of return to adequate O&M, the rate of under-investment in O&M is estimated to be 65 percent at present. Discrepancies between potentially high profitability and actual investment trends in rehabilitation and O&M indicate a compelling need to improve the designing and implementation of rehabilitation projects and O&M activities. Cost-effective methods for system rehabilitation and O&M with improvements in physical/engineering as well as institutional aspects must be pursued.

Meanwhile, the poor performance and gradual deterioration of the existing irrigation schemes have spurred a revolution in groundwater development. An increasing number of farmers have been installing agro-wells and irrigation pumps in the command and the highland. High rates of social and private return on investment in agro-wells and pumps have encouraged their rapid diffusion, with great prospects for still further diffusion in irrigation schemes. The management phase in Sri Lanka now involves both groundwater and surface water, and where groundwater use is prevalent, irrigation systems should be managed for conjunctive use to avoid high social costs.

Greater farmer participation, particularly in O&M, is desirable. However, the government still has a major role to play by providing public funds for rehabilitation/O&M and also by managing basin-level water resources to sustain productivity in the existing systems, avoiding overexploitation of groundwater, and controling pollution.

Development of irrigation in Sri Lanka needs a two-pronged approach. First, the government should vigorously act to devolve greater responsibility for O&M on user groups, while providing sufficient resources. It would be a great challenge to harmonize the process of farmers' greater involvement in O&M with the agro-well "revolution" that is essentially an activity of the individual farmer. Second, the government must adopt new policies and develop new institutional mechanisms for allocating water between agricultural and non-agricultural uses at the river-basin level and for regulating basin-level development of surface water and groundwater irrigation at macro-level. These steps are required to achieve higher productivity and sustainability of irrigated agriculture, assuring that in future too, irrigation remains the backbone of rural and agricultural development, just as it has been in the past.

Research Report 62

Irrigation Sector in Sri Lanka: Recent Investment Trends and the Development Path Ahead

M. Kikuchi, R. Barker, P. Weligamage and M. Samad

International Water Management Institute
P O Box 2075, Colombo, Sri Lanka

IWMI receives its principal funding from 58 governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR). Support is also given by the Governments of Ghana, Pakistan, South Africa, Sri Lanka, and Thailand.

This research was made possible through generous support from the Ford Foundation, New Delhi, SIDA (Swedish International Development Agency) and the Dutch Government.

The authors: M. Kikuchi is an International Water Management Institute (IWMI) Fellow and Professor of Agricultural Economics, Chiba University, Japan. R. Barker is a Principal Researcher, P. Weligamage is a Senior Research Officer and M. Samad is a Senior Researcher and the leader of the global theme on Water Resource Institutions and Policies, all of IWMI, Colombo, Sri Lanka.

The authors gratefully acknowledge valuable comments by Doug Merry, Thushaar Shah, Intizar Hussain, T. Jogaratnam and Gil Levine.

Kikuchi, M. ; R. Barker; P. Weligamage; and M. Samad. 2002. *Irrigation sector in Sri Lanka: Recent investment trends and the development path ahead*. Research Report 62. Colombo, Sri Lanka: International Water Management Institute.

/ irrigated farming / public investment / tube wells / pumps / rehabilitation / institutional aspects / groundwater / surface water / irrigation systems / farmer participation / river basins / pollution / sustainability / rural development / crops / agricultural development / peasants / rice / paddy cultivation / data processing / land development / infrastructure / technology / income / sprinkler irrigation / reservoirs / water delivery / water users / private investments / cropping systems / Sri Lanka /

ISBN: 92-9090-501-8

ISSN 1026-0862

Please send inquiries and comments to: *iwmi-research-news@cgiar.org*

Contents

Summary

The total investment in the irrigation sector of Sri Lanka, during the period of a decade and a half from the early 1980s to the mid-1990s, declined drastically to one seventh of its peak level in the early 1980s due a drop in public irrigation investments. Of the three types of public investment, new irrigation construction recorded the sharpest decline. Although the percentage for rehabilitation in the total irrigation investment increased, its absolute amount declined from the mid-1980s to the mid-1990s. The operation and maintenance (O&M) expenditure remained stagnant in the last two decades, and has declined since the mid-1980s. For the total irrigated area, which increased by 10 percent (50,000 ha) during this period, O&M expenditure per hectare declined considerably.

The total irrigation investment in the last half decade, showed a slight upward trend from its rock bottom level in the early 1990s. However, the relative composition of investment was entirely different from what it was before the early 1990s. Investment on rehabilitation increased and constituted the largest share in the total irrigation investment for the first time while investment in new irrigation construction continued to shrink.

Also remarkable is the rapid increase in private irrigation investment. The investment on agro-wells and irrigation pumps by farmers was negligible until the end of the 1980s, but increased rapidly in the 1990s, exceeding the O&M expenditure for the entire major irrigation schemes by a wide margin.

The rapid decline in new irrigation construction, which resulted from the drastic decline in its profitability and its sharply rising cost, in real terms, was a major factor choking off any incentive for new investment. The low rice price since the collapse of the commodity boom in the mid-1980s discouraged the government and international donor agencies from investing in new irrigation construction. Though very drastic, reduction in new construction investment is what can be expected at the present stage of development in irrigated agriculture.

The end of the construction phase signaled the beginning of the management phase with high profitability for major rehabilitation and water management improvement projects in the domain of public irrigation investment in Sri Lanka. But, the economic performance of some such projects was far less than expected, suggesting that project design and implementation with due attention to software and institutional focus are a prerequisite for the realization of their economic potential. A rough estimation of the required rehabilitation investment indicates that there was severe under-investment in the early 1990s. In spite of the high rate of return to adequate O&M, the rate of under-investment in O&M is estimated to be 65 percent at present. Discrepancies between potentially high profitability and actual investment trends in rehabilitation and O&M indicate a compelling need to improve the designing and implementation of rehabilitation projects and O&M activities. Cost-effective methods for system rehabilitation and O&M with improvements in physical/engineering as well as institutional aspects must be pursued.

Meanwhile, the poor performance and gradual deterioration of the existing irrigation schemes have spurred a revolution in groundwater development. An increasing number of farmers have been installing agro-wells and irrigation pumps in the command and the highland. High rates of social and private return on investment in agro-wells and pumps have encouraged their rapid diffusion, with great prospects for still further diffusion in irrigation schemes. The management phase in Sri Lanka now involves both groundwater and surface water, and where groundwater use is prevalent, irrigation systems should be managed for conjunctive use to avoid high social costs.

Greater farmer participation, particularly in O&M, is desirable. However, the government still has a major role to play by providing public funds for rehabilitation/O&M and also by managing basin-level water resources to sustain productivity in the existing systems, avoiding overexploitation of groundwater, and controling pollution.

Development of irrigation in Sri Lanka needs a two-pronged approach. First, the government should vigorously act to devolve greater responsibility for O&M on user groups, while providing sufficient resources. It would be a great challenge to harmonize the process of farmers' greater involvement in O&M with the agro-well "revolution" that is essentially an activity of the individual farmer. Second, the government must adopt new policies and develop new institutional mechanisms for allocating water between agricultural and non-agricultural uses at the river-basin level and for regulating basin-level development of surface water and groundwater irrigation at macro-level. These steps are required to achieve higher productivity and sustainability of irrigated agriculture, assuring that in future too, irrigation remains the backbone of rural and agricultural development, just as it has been in the past.

Irrigation Sector in Sri Lanka: Recent Investment Trends and the Development Path Ahead

M. Kikuchi, R. Barker, P. Weligamage and M. Samad

Introduction

Irrigation has been the most important strategic factor in the development of the peasant sector of Sri Lanka. Coupled with the diffusion of seed-fertilizer technology, irrigation development has tremendously contributed to increase domestic rice production. As a result, the rate of rice self-sufficiency has grown from about 40 percent in 1950 to over 90 percent in the 1990s. No one can deny the great success the irrigation sector has attained in this respect.

Having reached such a stage of development, however, the role of the irrigation sector is bound to change. The traditional target of attaining self-sufficiency in rice has been replaced by the new target of maintaining the current self-sufficiency level while enhancing the productivity of the irrigated land base by diversifying agriculture with high-value, non-rice crops and increasing the productivity of paddy cultivation (Barker and Samad 1998). This new target must be achieved not through the expansion of irrigated areas as in the past but through better water management in existing irrigation schemes. Is the irrigation sector in Sri Lanka adapting well to this new situation? What will be the future of the sector? This paper tries to shed light on these aspects by documenting recent trends in irrigation investment in both public and private sectors; the public investments by the government in pursuance of the study by Aluwihare and Kikuchi (1991), and the private investment by farmers, based on data collected from an island-wide field survey.

The next section of the paper provides a conceptual framework for the development phases of irrigated agriculture. This is followed by a presentation of the trends in government investments in new irrigation construction, rehabilitation, and O&M from 1948 to 1999 and also the trends in the rate of return to these investments. A comparison is made of needed and actual investments in rehabilitation and O&M. The trends in private investments in agro-wells and irrigation pumps made by individual farmers are then presented, together with the degree of diffusion of their various types in irrigation schemes in the dry zone, the economic performance of these well-pump investments, and their future prospects. The paper concludes with suggestions for attaining higher productivity and sustainability of irrigated agriculture.

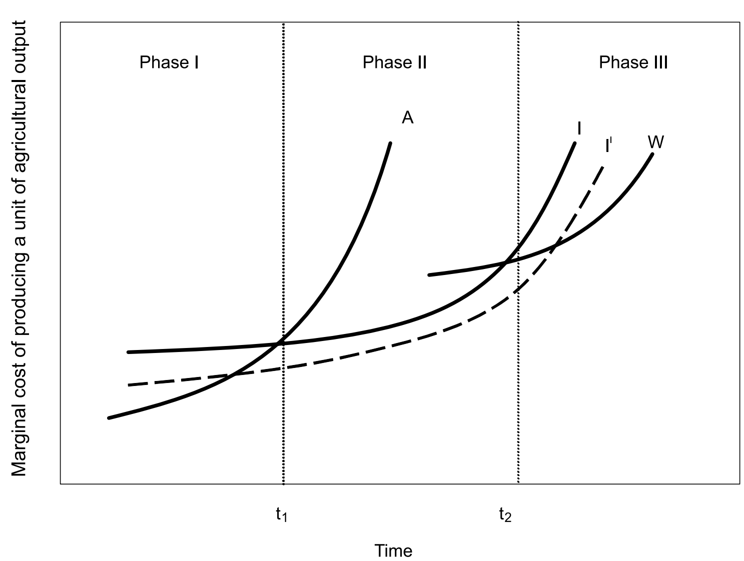
Development Phases of Irrigated Agriculture

Before proceeding to the data documentation, let us briefly consider the development paths of irrigated agriculture in monsoon Asia in the context of the development of land infrastructure based on Kikuchi and Hayami (1978) and Kikuchi, Maruyama and Hayami (2001), and locate the development experience of the irrigation sector in Sri Lanka within this conceptual framework. In figure 1, curve A represents the marginal cost of increasing agricultural output by opening new land, and curve I represents the marginal cost of raising agricultural production by constructing new irrigation facilities. At an early stage of agricultural development with abundant land resources, curve A remains horizontal and below curve I. As population pressure pushes the cultivation frontier into marginal areas, curve A would rise and cross curve I from below. When the economy reaches the cross-over point t_1, irrigation development becomes a more profitable base for agricultural growth than opening new land.

As the area under irrigation expands, the irrigation construction moves from the relatively easier and less costly sites to the more difficult and more costly ones. This means that curve I would also show a rising trend. The rising cost would eventually choke off the incentive to invest in new irrigation construction. The introduction of seed-fertilizer technology requires assured water supply as a prerequisite for its diffusion. This has the effect of reducing the cost of irrigation required to produce a unit of additional income in agriculture, as illustrated by the shift of curve I, downward to curve I’, and preserves the incentive to invest in creating new irrigation infrastructure. Given a certain level of agricultural technology, however, the marginal cost of irrigation construction would eventually start rising sharply as the potential sites for irrigation development are exhausted.

Curve W would then emerge as the third growth path, based on the enhancement of the

FIGURE 1.
Hypothetical development paths of land-based agriculture by means of land development: Marginal cost of producing a unit of agricultural output by new land opening (A), new irrigation construction (I) and improvements to existing irrigation infrastructure (W).



quality and performance of the existing irrigated land base that has already been developed.[1] There are many possible alternatives to attain this. The most conventional way is the rehabilitation and modernization of existing irrigation systems. The improvement of irrigation performance through better management, particularly with greater farmer participation in the O&M of the systems, is another. The conjunctive management of surface water and groundwater certainly increases the productivity of the existing irrigated land base. Agrowell development in existing command areas represents one example of such conjunctive use. There are other options, such as micro-irrigation (trickle irrigation, sprinkler irrigation, etc.,) and "melon vine" systems with small reservoirs built below the main reservoir to allow greater control over water deliveries at the farm level. It should be noted that none of the alternatives described above is mutually exclusive and all involve greater farmer participation in the management of water deliveries and maintenance of the system.

Using the data up to mid-1980s, Aluwihare and Kikuchi (1991) clearly show that the phase of new irrigation construction in Sri Lanka had been over by the early 1980s, though economic opportunities are wide open for improving the quality and performance of the existing irrigated land base. Their assumption that the irrigation sector shifted from the construction phase to the management phase can be interpreted as the shift in the development momentum from phase II to phase III in figure 1.

Nearly two decades have passed since the irrigation sector in Sri Lanka entered phase III. Changes are expected in phase III; in particular, the reduction in new irrigation construction investments, improvements in water management, enhanced O&M and the cost-effective rehabilitation/modernization of existing systems. Have these changes associated with public investments in the irrigation sector been taking effect? What about the private irrigation investments that had been nearly non-existent in phases I and II?

Public Irrigation Investments

First, through updating the data compiled by Aluwihare and Kikuchi (1991), let us look into the trends in public irrigation investments, made by the government with assistance from international donor agencies.

Investment Trends

The trends in government irrigation investments/ expenditures, in terms of 1995 constant prices and five-year averages, are shown in figure 2 and table 1, by investment/expenditure type. The total public investment in the irrigation sector showed a sharp decline from a very high peak during the decade between the early 1980s and the early 1990s. For the public investment as a whole, the declining trend bottomed in the early 1990s and the total government irrigation investment has kept at a low level since then. Earlier in the decade following the Korean War, from the mid-1950s to the mid-1960s, the

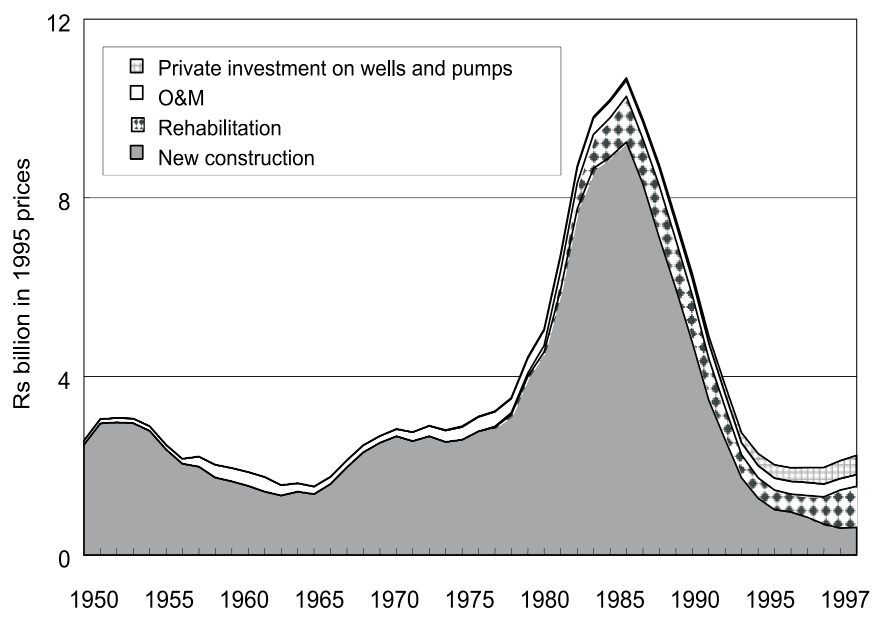
[1]It may seem anomalous to assume that agricultural production can be increased in the third phase by improving the irrigation performance of existing systems. So long as the existing systems are managed adequately for exploiting their full designed potential, there is no possibility of increasing production through management improvements. In reality, however, irrigation systems in developing countries are rarely operating anywhere near their potential due to faulty design and construction, neglected maintenance and inadequate operation. The development potentials along curve W have thus been created, at least partly, by undesirable conditions under which irrigation systems have been constructed and operated.

irrigation sector experienced a long period of decline in investment. The decline in the last decade, however, has been more severe in terms of its degree and duration. As a result, the total public irrigation investment declined to an unprecedented low level—in 1995 it was one seventh of the peak level in 1983.

Declining trends in the weight of public irrigation investments relative to the government budget, total public investments and total foreign assistance have also been evident (table 2). Irrigation, which was once the most important budget item in public investment and foreign assistance, now accounts for a very minor fraction. Irrigation still takes a quarter of the total public investments in agriculture, but the share of agriculture in public investment and foreign assistance has also been declining rapidly.[2]

Among the three types of public investment, new irrigation construction has experienced the sharpest decline and it is still declining (figure 2 and table 1); compared to its peak, the present level is far less than one tenth. Investment in irrigation rehabilitation, which had emerged in the mid-1970s, increased toward the mid-1980s, and decreased since then toward the mid-1990s to a level less than one half of the peak in the mid-1980s. However, it has shown slight increases since then. Total O&M expenditures have been stagnant or even declining since the mid-1980s in spite of some increases in the irrigated area for this period (table 1). The percentage share of new irrigation construction in the total irrigation investment, which was as high as 90 percent until the early 1980s, had decreased to less than 30 percent in the late 1990s, while rehabilitation

FIGURE 2.
Irrigation investments in Sri Lanka, 5-year moving averages, 1950-997.



[2]It should be noted that the war in the northern and eastern provinces in the last two decades must have affected the investment trends. The rapid decline in the share of public investments in the total government budget from the mid-1980s to the mid-1990s (table 2) might have resulted from the increasing share of the government budget spent for the war. It would have reduced the irrigation investments directly. For example, construction works in Mahaweli system A and Maduru Oya Right Bank projects were discontinued due to the war. We believe, however, that the investment depressing impacts of the war have not been so strong as to change the investment trends significantly, since the irrigation schemes in the northern and eastern provinces constitute only a small fraction of the entire irrigated land base in the country. Such a conjecture is supported by the fact that nearly the same investment trends are found for the same period in other Asian countries such as the Philippines (Kikuchi, Maruyama and Hayami 2000).

TABLE 1.
Irrigation investments in Sri Lanka by type of investment and their shares, 1950-97.[1]

	Investment (Rs billion in 1995 prices)					Share (%)				
	Public investment					Public investment				
	New construction	Rehabilitation	O&M	Private investment[2]	Total	New construction	Rehabilitation	O&M	Private investment	Total
1950	2.47	-	0.09	0.00	2.56	96	-	4	0	100
1955	2.36	-	0.11	0.00	2.46	96	-	4	0	100
1960	1.54	-	0.32	0.00	1.86	83	-	17	0	100
1965	1.59	-	0.16	0.00	1.75	91	-	9	0	100
1970	2.55	-	0.20	0.00	2.75	93	-	7	0	100
1975	2.86	0.01	0.33	0.02	3.22	89	0	10	1	100
1980	7.76	0.58	0.35	0.03	8.71	89	7	4	0	100
1985	7.11	1.16	0.40	0.08	8.74	81	13	5	1	100
1990	1.73	0.52	0.27	0.23	2.74	63	19	10	8	100
1995	0.69	0.61	0.28	0.37	1.96	35	31	14	19	100
1997	0.62	0.92	0.26	0.44	2.23	28	41	11	19	100

[1]Five-year averages centering on the years shown.
[2]Investments on agro-wells and irrigation pumps by farmers.

has increased its share to more than 40 percent. More than 50 percent of the public funds spent for irrigation investment now goes to irrigation rehabilitation.

A decline in the share in total public investment and in foreign assistance for agriculture as well as the irrigation sector is not necessarily a problem. For instance, a decline in agricultural investment share could be a genuine sign of rapid development in the non-agricultural sectors. In particular, it is no surprise at all to see a significant decline in new irrigation construction investment. Rather, in phase III, improvements in the performance of the existing irrigation systems are considered to be the major vehicle of agricultural development. But are these anticipated improvements taking place?

Rate of Return to Irrigation Investments

First, let us examine the change over time, in the rates of return to public investments on new irrigation construction and rehabilitation of existing irrigation systems. A few new construction and major rehabilitation irrigation projects were completed in the 1990s. With the data available on some of these recent projects, the rates of return to public irrigation investment of different types are re-estimated. Except for some assumptions that are modified to represent changes in the rice sector during the last decade, the estimation follows the procedure adopted by Aluwihare and Kikuchi (1991).

TABLE 2.
Government budget, public investment and public irrigation investment, 1950-97.[1]

	Value (Rs billion in 1995 prices)						
	Total government budget	Total public investment	Total public investment in agriculture	Total foreign assistance	Total public irrigation investment		
	(1)	(2)	(3)	(4)	(5)		
1950	37	8	4	-	3		
1955	50	10	5	1	2		
1960	72	13	7	1	2		
1965	90	16	8	4	2		
1970	117	21	13	8	3		
1975	150	27	13	15	3		
1980	176	49	16	39	9		
1985	165	50	24	31	9		
1990	191	36	10	29	3		
1995	231	32	6	23	2		
1997	230	31	5	18	2		
	Share in percent						
	(5)/(1)	(5)/(2)	(5)/(3)	(5)/(4)	(3)/(1)	(3)/(2)	(3)/(4)
1950	7.0	33	72	-	10	46	-
1955	4.9	25	51	168	10	48	328
1960	2.6	14	28	129	9	52	459
1965	2.0	11	21	39	9	51	185
1970	2.3	13	20	33	11	63	160
1975	2.1	12	25	22	9	47	86
1980	4.9	18	54	22	9	33	41
1985	5.3	17	36	28	15	48	79
1990	1.3	7	25	9	5	28	34
1995	0.8	6	35	9	2	17	24
1997	1.0	7	44	13	2	16	29

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

The rate of return to irrigation investments is analyzed by estimating the cost-benefit ratio and the internal rate of return. The following estimation formula is used for the cost-benefit ratio (C/B):

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

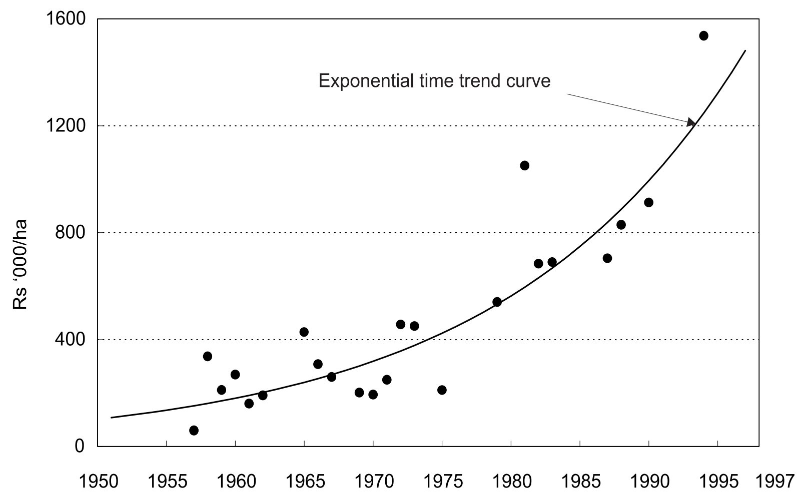
$$= [K/(R-c)][pi^{2} (1+i)^{n+m}] / [(1+i)^{n+p+1} - (1+i)^{n+1} - pi]$$

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 of the irrigation scheme constructed/rehabilitated,
p = number of years between the year when the benefit partially starts accruing and the year of project completion (defined for $p^{3}2$),
m = average gestation period of the capital investment, and
i = interest/discount rate (assumed to be 10 percent).

The internal rate of return (IRR) is defined as r that satisfies the following equation:

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

FIGURE 3.
Changes in the real capital costs per hectare (including capital interest evaluated at 10 percent per annum) of new irrigation construction, 1950-1997, in 1995 constant prices.



It should be noted that the first term of the benefit formula is introduced to take into account the cases where a part of the benefit starts accruing before project completion, assuming linear increases in benefits from zero to the full benefit level.

Throughout the analysis, 1995 prices are used for the constant-price estimation, and the GDP implicit deflator for construction is adopted whenever deflation is necessary.

New irrigation construction: For new irrigation construction projects, additional data are available only for Zones 3-6 of the Mahaweli System C, which was completed in 1994 (World Bank 1993). A time-series of capital cost per ha is compiled using 50 new irrigation construction projects, including this new set of data. In this compilation, the unit cost of each project is recorded in the year the project was completed,[3] and, in case there was more than one project completed in a year, the weighted average is taken using the system command area as weight. The resulting series in 1995 constant prices is presented in figure 3. Fitting the exponential time- trend curve to this series gives the following result:

$$K^* = -106.3 + 0.057\,t \quad R^2 = 0.713$$
$$\quad (-6.84) \quad (7.23)$$

where: K^* = capital cost per ha including capital interest (Rs 1,000 in 1995 prices),
t = time
R^2 = coefficient of determination, and the figures in parentheses are t-ratios.

The unit capital cost estimated by this trend curve is used as the cost of new irrigation construction.

[3]In Aluwihare and Kikuchi (1991), it was recorded as in the year the project reached 90 percent completion.

On the benefit side, rice is assumed to be the crop to be grown, since rice has remained as the main crop in major schemes in the last and the previous decades. Except for the areas equipped with agro-wells and irrigation pumps, the extent planted with other field crops (OFCs) in major irrigation schemes was negligible in spite of the major efforts made by the government for crop diversification in rice-based major schemes. Note also that we have not included the benefits and costs of hydropower that occur in some of the larger projects such as Mahaweli.

In order to analyze the complementary relationship between irrigation and seed-fertilizer technology, three different seed-fertilizer technology levels are assumed: 1) traditional varieties with 0 kg per ha of nitrogen application (TVN=0 kg), 2) old-improved varieties with 70 kg per ha of nitrogen (OIV N=70 kg) and 3) new/ improved varieties with 140 kg per ha of nitrogen (NIV N=140 kg). The rice output for each technology level is estimated by the national average fertilizer response function at the farm level for each variety group, which is derived from the fertilizer response function at the experiment station level. The response functions at the experiment station level are re-estimated using the data presented in Kikuchi and Aluwihare (1990).[4]

The benefit flow is measured as an increase in agricultural income (gross value-added), assuming zero opportunity cost for labor.[5] The total current input in rice production is assumed to be 2.5 times the cost of nitrogen. For the constant price estimation, the average farm-gate prices for 1993-97 are used for both rough rice and nitrogen. In the current price estimation, the farm-gate equivalent border prices are used for evaluating the value added.[6] The cropping intensity of the systems is assumed to be 1.4, which is the average for all the major irrigation systems for the entire study period. The O&M cost is assumed to be Rs 1,830 per hectare in 1995 prices. This is the level that the Irrigation Department set as the "desired level" of O&M for major irrigation systems (IIMI 1989). It should be noted that many independent studies on O&M needs, including those with detailed engineering examination, come up with approximately this level of desired O&M intensity (Ariyaratne 1990; Sheladia 1990; World Bank 1993). Finally, the usable life of newly constructed irrigation scheme (n) is assumed to be 50 years, following the convention in the cost-benefit analysis for irrigation projects.

The results of constant-price estimation are presented in figure 4 and table 3. The re-estimation of the profitability of new irrigation construction does not change the conclusions obtained in the earlier study. The trends of C/B ratios for the different levels of seed-fertilizer technology in figure 4 simulate well the marginal cost curves I and I' in figure 1. In spite of some favorable changes in the assumptions for the latest technology level (NIV N=140 kg),[7] the C/B ratio curve exceeds unity in the early 1980s, and reaches a level nearly two by the mid-1990s. In terms of IRR, the present level of profitability of new irrigation construction investments is as low as five percent.

[4]For the estimation of rice fertilizer response functions, see annex B of this paper.

[5]Zero opportunity cost of labor is a plausible assumption in dry zone irrigation systems. It is particularly so for the case of new irrigation construction that has mostly been implemented in the dry zone as colonization projects involving farmers' resettlement. It should be plausible to think that new settlers had a difficulty in finding productive employment opportunities in their original place. If so, the opportunity cost of their labor should be quite low, if not zero.

[6]As to the border prices of rice and nitrogen, see Kikuchi et al. 2000. The prices and other parameters related to the estimation are presented in annex B.

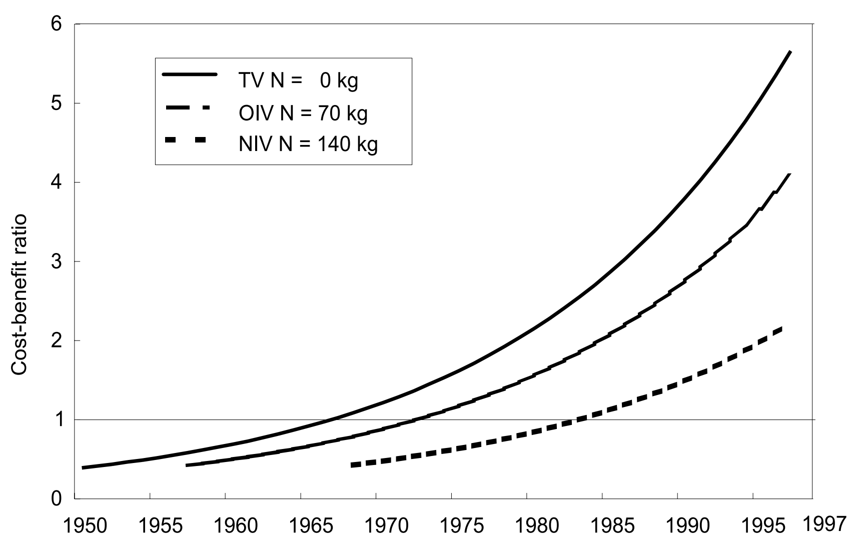
[7]For example, the yield is increased nearly by one metric ton per hectare for this technology level.

TABLE 3.
Cost-benefit ratios and internal rate of return on investments in new irrigation construction, by level of seed-fertilizer technology, five-year averages, based on 1995 constant prices.[1]

	Technology Level					
	Traditional varieties N=0 kg		Old improved varieties N=70 kg		New improved varieties N=140 kg	
	Cost-benefit ratio	Internal rate of return %	Cost-benefit ratio	Internal rate of return %	Cost-benefit ratio	Internal rate of return %
1950	0.39	22				
1955	0.52	18				
1960	0.69	14	0.50	18		
1965	0.92	11	0.66	14		
1970	1.22	8	0.88	11	0.48	19
1975	1.62	6	1.17	9	0.63	15
1980	2.15	5	1.56	7	0.84	12
1985	2.86	3	2.07	5	1.12	9
1990	3.80	2	2.76	3	1.49	7
1995	5.05	1	3.66	2	1.98	5
1997	5.66	0.5	4.11	1.7	2.21	4.5

[1]For the estimation formula and assumptions, see the text and annex A.

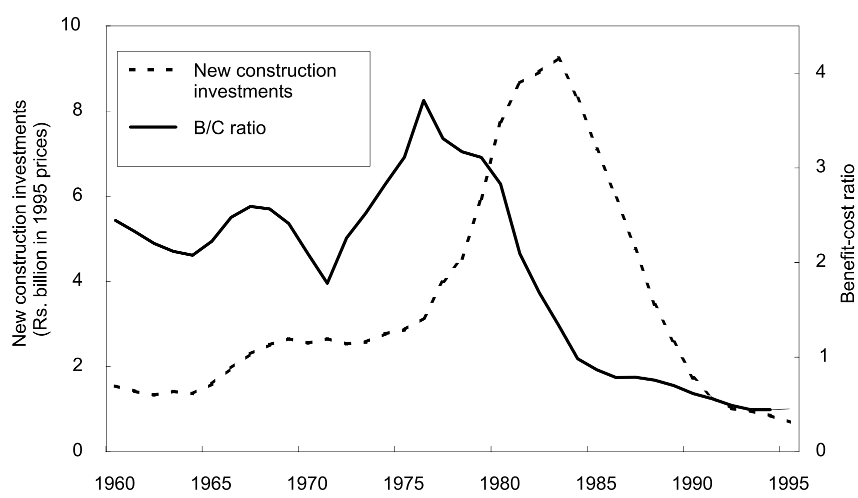
FIGURE 4.
Changes in cost-benefit ratio of new irrigation construction investments, 1950-1997, by level of seed-fertilizer technology, based on 1995 constant prices.



As we see in figure 2, the new irrigation investments have been declining sharply since the early 1980s. This corresponds to the long-run trend in the C/B ratios. However, the decision of the government and international donor agencies about new irrigation construction investments might have depended more on their short-run profitability. This proposition is supported by figure 5, which shows the trends in the benefit-cost ratio and in new construction investments expressed in billions of rupees at 1995 prices. The benefit-cost (B/C) ratio for new irrigation construction is estimated as follows: 1) the benefit is evaluated by applying current international prices (converted to the farm-gate equivalent) of rough rice and nitrogen, 2) the cost, both capital and recurrent, is evaluated in current prices, and 3) the B/C ratios for three technology levels thus estimated are aggregated into a single series using the percentage shares of the area planted with each type of rice variety in each year as weight.

It is apparent that the investment peak in the early 1980s was created by the exceptionally high profitability of the investments that resulted from high international rice prices during the two food crises in the 1970s. The decline in the B/C ratio after this peak has been paralleled by the equally sharp decline in the investments with about a 7-year lag.[8] The pace of decline in the profitability of the investments, has slowed down slightly since the mid-1980s, inducing the same change of pace in the investments, but there has been no sign that the declining trend is reversed. The most decisive factor behind this decline in the current B/C ratio has been the decline in the international rice price. This decline has been brought about by the irrigation development in preceding years, and the successful diffusion of the seed-fertilizer technology in the irrigated land-base of developing countries in Asia as a whole. It is worth noting that consumers and not farmers have been the main beneficiaries of irrigation investments and seed-fertilizer technology.

FIGURE 5.
Changes in benefit-cost ratio of new irrigation construction investments evaluated at current world prices and total new irrigation construction investments in 1995 constant prices, five-year moving averages, 1960-1995.



[8]Note that this lag corresponds to the average gestation period of capital investments for new irrigation construction, as assumed in the cost-benefit analysis.

Rehabilitation and water management improvement: We failed to find new data for water management projects. However, new sets of data are available for four rehabilitation/ modernization projects: the Village Irrigation Rehabilitation Project (VIRP) completed in 1990, the Irrigation System Management Project (ISMP) completed in 1992, the Major Irrigation Rehabilitation Project (MIRP) completed in 1994, and the National Irrigation Rehabilitation Project (NIRP) completed in 1999. It should be noted that VIRP was to rehabilitate small village tank systems (mostly minor irrigation schemes), and so was NIRP. Including these three projects, the rates of return of rehabilitation and water management projects are re-estimated, based on the 1995 constant prices. Similar to the new irrigation construction projects, some modifications in the parameters and assumptions are made for the projects that were analyzed in Aluwihare and Kikuchi (1991).[9] For the same reason as for the new construction projects, rice is assumed to be the crop grown.

The results of the estimation are summarized in table 4, together with the rates of return of new construction projects in the 1980s and 90s. In the 1980s, the marginal cost of increasing agricultural output through new irrigation construction (curve I or I' in figure 1) began to rise sharply, cutting the C/B ratio = 1 line from below (figure 4). At this point in time, that is roughly the mid-1980s, the irrigation sector moved in to phase III with curve W located below curve I (or I'). In phase III, it is expected to be more profitable to increase agricultural output through improving the quality and performance of the existing irrigated land-base. Some rehabilitation/water management projects have satisfied such expectations, but some others have not.

Among the major rehabilitation projects analyzed, the Gal Oya Project and the ISMP show rates of return, significantly higher than those of new construction projects. The internal rate of return of the Gal Oya Project is 26 percent and the C/B ratio is 0.37.[10] The Tank Irrigation Modernization Project (TIMP), the first of the major rehabilitation projects undertaken in Sri Lanka, met with limited success. The major focus of the TIMP was physical improvements, with scant attention to institutional development. The project inevitably had many defects in its design and implementation. Nonetheless, it provided useful lessons for implementing future irrigation rehabilitation projects.[11]

It is rather surprising to see very low rates of return for the VIRP and the MIRP; their C/B ratios, though marginally lower than for new construction projects in the corresponding period, are equal to or more than unity. As was the case with Gal Oya Project and the ISMP, these projects could have benefited from the lessons from the TIMP, that clearly

[9]Basic parameters and assumptions are presented in annex table a-5.

[10]The estimated economic performance of the Gal Oya Project in this paper is better than that in Aluwihare and Kikuchi (1991) due to a favorable assumption on the post-project yield level made in this paper based on Amarasinghe et al. (1998), (see annex table a-5). It should also be noted that the reliability of the estimate of benefits due to the project is highest for the Gal Oya Project because of data availability from many intensive post-project studies conducted for this project. The estimate of project benefits for the ISMP, which was a very innovative project laying heavy emphasis on institutional aspects of water management with least unit capital cost among the major rehabilitation projects implemented thus far in the country, is not as reliable as the estimate for the Gal Oya Project, because of paucity of data on the post-project state.

[11]The IRR of the TIMP, is estimated to be 10 percent, which is lower than the estimate in 1986 prices (Aluwihare and Kikuchi 1991), in spite of the assumptions made in favor of the benefit in the re-estimation. This is due to the fact that the prices related to construction have increased faster than the price of rice between 1986 and 1995.

TABLE 4.
Rates of return on irrigation investments in recent decades: new irrigation construction, rehabilitation / water management improvement, and O&M, based on 1995 constant prices.

	C/B ratio	Internal rate of return (%)
I. New construction projects:[1]		
1980	0.8	12
1985	1.1	9
1990	1.5	7
1995	2.0	5
II. Major rehabilitation projects:[2]		
TIMP; 1984	1.04	10
Gal Oya; 1987	0.37	26
VIRP; 1990	1.09	9
ISMP; 1992	0.60	17
MIRP; 1994	1.02	10
NIRP; 1999	0.88	12
III. Water management projects:[3]		
Kimbulwana; 1980	0.1	86
Pimburettawa; 1989	0.2	64
Nagadeepa; 1989	1.8	-22
IV. Desired level of O&M:[3]		
T=30	0.2	34
T=40	0.3	23
T=50	0.4	17

[1] For the technology level "New Improved Varieties; N=140kg."

[2] Years after the names of projects stand for the years when the projects completed. For basic parameters/assumptions in the estimation, see annex table a-5.

[3] T stands for the year after the construction when, with no maintenance at all, the benefit flow due to irrigation ceases to accrue. For details, see text.

demonstrated that physical improvements alone will not be sufficient to improve performance (Ratnayake 1997). Unlike the more successful Gal Oya project and the ISMP, the VIRP and the MIRP were heavily focussed on engineering works with less attention to the institutional and software aspect. This may explain the difference in the investment performance between them. In particular, the degree of failure of VIRP seems to be very serious. Under VIRP, the unit capital cost of rehabilitating minor irrigation schemes was as high as Rs 65,000 per hectare, as compared with Rs 60,000 per hectare for the Gal Oya Project and Rs 40,000 per hectare for the ISMP, all in 1995 prices. There must have been some fundamental defects in the design and implementation of the project, which the project completion report(PCR) (World Bank 1992) fails to point out.

It must be noted that our estimates of the rate of return for TIMP, VIRP, MIRP and NIRP are most likely overestimated.[12] For TIMP, the reasons for overestimation are explained in Aluwihare and Kikuchi (1991). For VIRP, MIRP and NIRP, we use optimistic estimates regarding the increase in cropping intensity—the most critical parameter in determining the benefit flow of this type of project—adopted from their PCRs

[12] As noted earlier, the rate of return of the ISMP may be overestimated, but the degree of possible overestimation for the ISMP is much less than for the other three projects.

(World Bank 1992, 1995 and 1999). It may be worth mentioning that these PCRs report an IRR of 16 percent, 20 percent and 14 percent for VIRP, MIRP and NIRP, respectively. These values, especially for VIRP and MIRP, are overestimated. In the case of VIRP, the project benefit is "inflated" by an assumption that the irrigation systems deteriorate quickly without the rehabilitation project; the value of the crop that is forgone because of the deterioration is included as a part of the benefit of the project. This assumption is invalid, because the "desired level" of O&M, which is included in the cost-benefit analysis, minimizes the deterioration of the systems after the project.[13] In the case of MIRP, the project benefit is "inflated" due to the assumption of a large yield increase not directly caused by the rehabilitation project.

Water management improvement projects can be extremely profitable as the Kimbulwana and Pimburettawa projects reveal. However, there can also be failure cases, as evidenced by the Nagadeepa Project.[14] Lessons that can be learned from these experiences are found in Aluwihare and Kikuchi (1991).

O&M expenditure: All the estimated rates of return for irrigation investments thus far in this section assume that O&M of irrigation systems is carried out at the 'desired' level after the project. What about the rate of return to recurrent investments in O&M activities? In spite of the critical importance of O&M in maintaining the performance of irrigation systems, there have been few attempts to estimate the rate of return to O&M expenditures. This is partly because no reliable estimate is available about the possible benefit for recurrent investments on O&M activities. Let us try here to estimate a rough order of the rate of returns for O&M expenditures.[15]

As mentioned earlier, the life span of a newly constructed irrigation system is conventionally assumed to be 50 years. It is expected that the 'desired' level of O&M expenditures, maintains the benefit stream due to irrigation during this life span. As a matter of fact, however, rehabilitation projects have been implemented in many systems much earlier than the end of this life span. For example, the systems included in the TIMP were selected for rehabilitation, on average, only 11 years after the completion of their new construction projects. In other rehabilitation projects implemented in Sri Lanka so far, this duration rarely exceeds 20 years.[16] This is a definite sign that the irrigation systems have been deteriorating rapidly due to the less-than-desired level of O&M.

[13]In other words, they include the benefit attributable to the O&M expenditures in the benefit of the rehabilitation project.

[14] Aluwihare and Kikuchi (1991) estimated the IRR of the Nagadeepa Project to be six percent, which is apparently a mistake.

[15]Readers should be warned that our values for the rate of return to O&M expenditures may be subject to some overestimation. The level of the rate of return depends critically not only on T but also on the shape of the deteriorating curve along which the quality and performance of irrigation systems deteriorate over time if there is no O&M at all. The curve may have a shape in which the deterioration proceeds more slowly than the case of the parabolic shape assumed here. In the real world, if an irrigation system begins to deteriorate because of the lack of maintenance, the system management as well as farmers may take a series of adjustments that can be made to counteract the deterioration; for example, using freeboard to compensate for loss of flow capacity at the system level, and increased intensity of management at the farm level. The adoption of these adjustments may delay the emergence of the adverse impacts of the lack of maintenance. It should be pointed out, however, that these adjustments are not costless. For example, intensified management at the farm-level in order to counteract quality deterioration entails a certain level of cost, which is a part of foregone benefits of the adequate level of O&M. In any case, how an irrigation system deteriorates without maintenance is left to be an important research area in the future. Here, we present the estimation results of the rate of return to O&M, based on the assumption of parabolic-shaped deterioration curves for illustrating the importance of O&M.

[16]This duration was 15 years for the Gal Oya Rehabilitation Project and 19 years for the MIRP.

It is difficult to identify how rapidly an irrigation system deteriorates if no maintenance activity is done at all. As an illustration, let us assume that with zero maintenance, the performance of an irrigation system deteriorates over time in a parabolic way such that the benefit stream goes down to zero T years after its construction. The difference between the total benefit stream for the full 50-year life span with the desired level of O&M, and that for the reduced T-year life span with zero maintenance, thus gives the benefit of the desired level of O&M. Assuming the technology level of NIV N=140 kg, the desired O&M level of Rs 1,830 per hectare, and the time discount rate of 10 percent, the C/B ratio and the IRR of the recurrent O&M investment are estimated for different levels of T (table 4).[17] In terms of IRR, the estimated rate of return ranges between 34 percent for T=30 years and 17 percent for T=50 years.[18] It may be unlikely that an irrigation system collapses within 30 years if there is no maintenance at all, and it is even more unlikely that it takes 50 years for the benefit flow to cease accruing. In the environmental context of the dry zone in Sri Lanka, it appears reasonable to suppose that the reduced life span in reality is closer to T=30 rather than T=50. In any case, the results of our illustrative estimation suggests that the recurrent investment on O&M activities has a very high rate of return. Its rate of return could be higher than that of a major rehabilitation project, and significantly higher than that of new construction investment in the 1990s.

Altogether in this section, we can conclude that the irrigation sector in Sri Lanka has been in phase III of irrigated agriculture since the early 1980s; curve W is located below curve I (or I'). However, it is much more difficult for public irrigation investments to realize the profitability envisaged by curve W than to realize that envisaged by curve I. Deliberate project design and implementation with due consideration on the software and institutional aspects of the project is a prerequisite for the rehabilitation/ water management project in phase III to be successful. It should also be pointed out that the potentially high rates of return of phase III projects do not seem to have induced a steady increase in investments on this type of project in the recent decade. On the contrary, as observed in figure 2 and table 1, investments in irrigation rehabilitation had decreased considerably since the mid- 1980s up to the mid-1990s, and O&M expenditures were declining since the mid-1980s.

Investment Needs versus Actual Investments

The estimated trend of the profitability of new irrigation construction clearly explains the rapid shrink of new construction investments in recent years. However, it appears that the difficulties in dealing with rehabilitation and water management projects have resulted in under-investment in these projects, despite their potentially high rates of return. Under-investment

---

[17]The formula for the C/B ratio is given as follows:

$$C/B = \left[\sum_{t=1}^{50} c / (1+i)^t \right] / \left\{ \sum_{t=1}^{T} [R - (a - bt^2)] / (1+i)^t + \sum_{t=T}^{50} R / (1+i)^t \right\}$$

where R = annual income generated by irrigation system, c = annual O&M expenditure, t = time, and a and b = parameters so that R goes down to zero at t = T. The formula for IRR is defined accordingly.

[18]If systems deteriorate linearly, instead of in parabolic shape, the IRR of O&M investment is as high as 106 percent even for T=50.

in O&M, which has been a chronic problem ever since, appears to have grown even more acute in recent years. One reason for this under-investment in the past has been the willingness of the World Bank and other donors to fund the rehabilitation of even those projects that have been constructed fairly recently. As long as this prospect exists, there is a tendency in governments to allow irrigation systems to deteriorate at a fairly rapid rate.

In order to have a fair idea about the seriousness of the under-investment in the irrigation sector, let us estimate the investment needs of this sector. Since we expect that public irrigation investments in phase III are principally limited to rehabilitation/water management projects and O&M, we focused on their investment needs.

Rehabilitation investments: Capital investments required to rehabilitate irrigation systems could vary depending on various conditions specific to each system. In fact, the capital cost per ha of the rehabilitation projects implemented thus far in Sri Lanka ranges from Rs 38,000 for ISMP to Rs 60,000 for the Gal Oya, and further to Rs 131,000 for TIMP.[19] The experience in the past, however, indicates that under ordinary conditions it becomes progressively difficult for a major rehabilitation project to attain a reasonable level of economic performance if the unit capital cost becomes higher than the Gal Oya level.[20] As the minimum level of rehabilitation cost, let us assume here the capital cost of Rs 60,000 per ha in 1995 prices.[21]

The total irrigated area in Sri Lanka at present is about 500,000 ha, consisting of 320,000 ha under major irrigation schemes and 180,000 ha under minor irrigation schemes. Assuming 25 years as the lifetime of a rehabilitation project, the annual need of funds for rehabilitating irrigation systems is calculated to be Rs 1.2 billion. Note that this is considered the minimum requirement. The actual level of the investments in 1997, which is Rs 0.92 billion (table 1), is about 75 percent of this required level. The actual level is an under-investment, but the degree of under-investment is not so serious. It should be noticed that the actual investment was 50 percent of the required level in 1995 and 40 percent in 1990.

O&M expenditure: In the cost-benefit analysis, the "desired level" of O&M expenditures is assumed to be Rs 1,830 per hectare for major irrigation schemes, and Rs 940 per hectare for minor irrigation schemes, both in 1995 prices. The total funds required annually for operating and maintaining the irrigation systems at the "ideal" state is estimated to be Rs 0.75 billion. Compared to this required level, the actual O&M expenditures in 1997 amount only to 35 percent.[22] Thus the O&M of irrigation systems is highly under-invested.

It should be mentioned that who shoulders O&M costs does not matter in the present context. As in many other developing countries, the participation of farmer-beneficiaries in O&M has been emphasized in Sri Lanka. Transfer of O&M responsibility of irrigation facilities below the

[19]See annex table a-5.

[20]It should be emphasized that the unit capital cost for rehabilitation of this level is Rs 60,000/ha or US$1,200/ha in 1995 prices at the exchange rate in 1995. If necessary, the capital cost for rehabilitating an irrigation system is higher than this level, an extremely high level of physical performance is required for such a project to attain an economically justifiable level of rate of return.

[21]Another choice is to represent the minimum rehabilitation requirement by the unit capital cost of the ISMP. But, we do not take it, mostly because the economic performance of this project is not as clear as that of the Gal Oya project.

[22]World Bank (1995) reports that the O&M fund actually allocated in 1993 to the major irrigation systems under irrigation development and irrigation management development was less than 30 percent of the "desired level."

distributing canals, to water users, has in fact been the stated policy of the government since a decade ago (Samad and Vermillion 1999). The promotion of farmer participation through formation of effective farmer organizations has been of central importance in many water management improvement projects, including those analyzed in this paper. In many countries, irrigation management transfer (IMT) aims not only at enhancing system performance but also at reducing government costs. In the case of Sri Lanka, however, the higher involvement of farmers in O&M does not necessarily mean a significant reduction in the government O&M expenditures; by and large the government is still responsible for providing O&M provisions. Therefore, the estimated rate of under-investment in O&M needs little adjustment in this respect.[23]

Private Irrigation Investments

As in many other countries in monsoon Asia, a salient feature of the irrigation sector in Sri Lanka during the last decade has been the rapid diffusion of agro- wells[24] and small irrigation pumps among farmers in irrigation systems, which we specify as a possible option in phase III. Needless to say, agro-wells and pumps are private investments made by individual farmers, except for the subsidy, if any, given to them.[25] In this section, we present the trends of these private investments, based on the data we collected from field surveys in the dry zone.

Three points should be noted at the outset. First, our estimation of private irrigation investments is confined to agro-wells and pumps owned by farmers in irrigation schemes, minor as well as major, in the dry zone. All investments in constructing and rehabilitating minor irrigation schemes made by the government are included in the public investments, but farmers may have spontaneous investments too in the form of labor mobilized for construction, rehabilitation and maintenance of their schemes. Such investments made collectively by farmers in minor irrigation schemes are not accounted for in this study as data are not available. Though expected to be a small fraction of the total investments of farmers on agro-wells and pumps, such investments of upland farmers who do not cultivate paddy in irrigation schemes and by farmers in the wet zone are not included, too. Second, our estimation depends on a very small sample, and the estimated results would constitute only a hunch regarding the magnitude of farmers' investments on agro-wells and pumps. Third, however, fragmented available data on the

[23]No data are available as to the degree of savings in financial outlay due to the participatory approach. The fact that all the recent project completion reports, either of new construction or of rehabilitation, unanimously point out inadequate O&M resulting from insufficient funds as the detriment against the sustainability of the projects, suggests that these savings, if any, are not sufficient to counteract the declining trend in financial outlay for O&M per unit of irrigated area.

[24]In this paper, an agro-well is defined as a well, the water from which is fully or partially used for crop cultivation.

[25]There are some pump irrigation schemes that were constructed and managed by the government. The pumps of these schemes are large, not like the ones farmers install for their own use.

diffusion of agro- wells and pumps in Sri Lanka are all consistent with our estimation.[26]

Diffusion of Agro-wells and Pumps and Investment Trends

First, let us observe the total numbers of agro-wells and irrigation pumps in the irrigation schemes in the dry zone at the turn of the century (table 5). In the context of the dry zone in Sri Lanka, agro-wells can be classified into, at least three types: lined dug-wells, unlined dug-wells and tubewells. The first two types are open dug wells of 14 ft to 22 ft diameter and 14 ft to 40 ft deep.[27] The lined dug-well has its wall lined with cement, whereas in the unlined dug-well the wall is left just as dug using a machine shovel. Tube wells make use of a 2 to 6 inch diameter plastic pipe implanted vertically into the ground down to the underground water table that is 15 to 60 ft deep.[28] It should be mentioned that the type of well that has been promoted by the government and non-profit making organizations through subsidies is the lined dug-well.[29] In contrast, the unlined dug-well and the tubewell have been diffused entirely under farmers' own initiative.

For all three types of wells, water is usually lifted up by a 2-inch pump, operated by diesel or kerosene engine of 2.5 to 5 HP—the most popular size being around 3.5 HP—with which a 2-inch pipe is used for distributing water to the field.[30] Unlike the tubewell for domestic purposes which is usually operated by a manual pump, the tubewell for agriculture always has an engine or a motor driven pump. Besides lifting groundwater, farmers use pumps for lifting water from rivers, canals or tanks (dead storage in particular) to irrigate their crops.

TABLE 5.
Numbers of dug wells, tubewells and irrigation pumps by region and by type of irrigation scheme, in the command and highland areas of irrigation schemes in the dry zone of Sri Lanka, by the end of 2000.

	Major schemes		Minor schemes		Total	
	No. (1000 units)	%	No. (1000 units)	%	No. (1000 units)	%
Lined dug well	8.8	27	23.6	73	32.5	100
Unlined dug well	8.2	100	-	-	8.2	100
Tube well	0.3	3	9.5	97	9.8	100
Irrigation pumps	38.8	36	68.1	64	106.9	100

Source: Kikuchi et al. 2001.

[26]For details on our surveys, estimation processes and the results of estimation, see Kikuchi et al. 2001.

[27]1 foot = 0.3048 m.

[28] 1 inch = 2.54 cm.

[29]The most popular government agencies that grant a subsidy for constructing lined dug-wells are the Agricultural Development Authority (ADA) and the Provincial Councils (PC). Various non-profit organizations and non-government organizations, such as International Fund for Agricultural Development (IFAD), Asian Development Bank (ADB), OISCA Japan, and Isuru Foundation, extend a subsidy and subsidized loan for well construction. There has been no subsidy program for irrigation pumps, but there have been some loan programs.

[30]The virtual nonexistence of electrically powered motors for pumping up groundwater in irrigation schemes is a salient feature of the well-pump diffusion in Sri Lanka when compared with other countries in south Asia (Shah 1993). Upland cultivation in the Kalpitiya area in the Puttalam district is an exception.

TABLE 6.

Percentages of wells with subsidy and those in highland, depth of wells, purposes and sources of pumping water, in irrigation schemes in the dry zone of Sri Lanka, by the end of 2000.

		Major irrigation schemes	Minor irrigation schemes	Total[1]
I.	% of agro-wells subsidised	39	44	41
II.	% of agro-wells in high-land	72	74	73
III.	Purpose of well/pumping (%)			
	Paddy cultivation	4	15	8
	OFC cultivation	96	85	92
IV.	Source of water (%)			
	Groundwater	37	46	40
	River, canal or tank	63	54	60
V.	Depth of open dug-well (feet)			
	Min	18	18	18
	Max	28	40	40
	Average	22	24	23

[1]Weighted averages are shown for the dry-zone total, using irrigated area as weights.

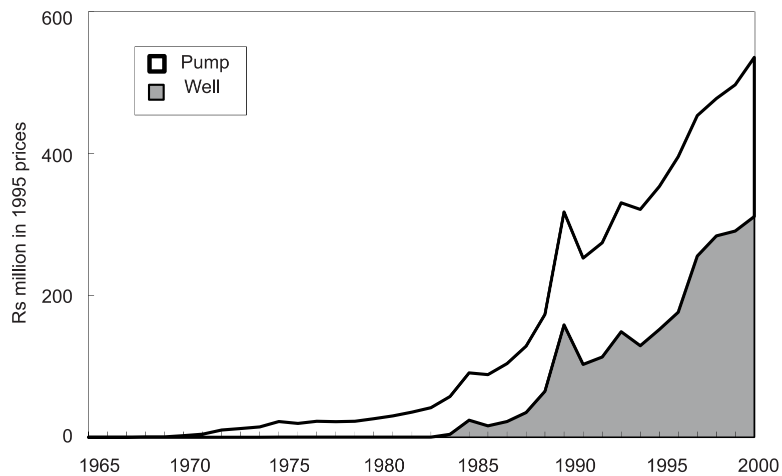
Source: Kikuchi et al. 2001.

As shown in table 5, it is estimated that there are about 33,000 lined dug-wells, 8,000 unlined dug-wells, 10,000 tubewells, and 100,000 irrigation pumps in the irrigation schemes in the dry zone. More than 70 percent of lined dug-wells are found in minor irrigation schemes. Unlined dug-wells are found only in major irrigation schemes, while tubewells are found mostly in minor schemes. In the case of irrigation pumps, more than 60 percent are owned by farmers in minor schemes. About 10 percent of farmers in irrigation schemes, both major and minor, own agro-wells, while about 15 percent own irrigation pumps (Kikuchi et al. 2001).

Some features of agro-wells and irrigation pumps are summarized in table 6. Since 1989, the government has been making major efforts to promote lined dug-wells in both major and minor irrigation schemes in the dry zone through extending a subsidy to farmers. However, there are many agro-wells that receive no subsidy. For the three types combined, 45 percent of agro-wells received the government subsidy. Even for lined dug-wells alone, this percentage is less than 50 percent and there has been no subsidy program for unlined dug-wells and tubewells. All this indicates that the majority of farmers who own agro-wells made their investment decision by themselves.

In irrigation schemes, agro-wells can be set up either in the command area or in the highland. Both in major and minor schemes, the distribution of agro-wells between the command and the highland is about 30:70—more agro-wells are set up in the highland than in the command (table 6). In major and minor schemes alike, farmers use pump water mostly for irrigating other food crops (OFCs). They use pumps for irrigating paddy occasionally, only when water from their gravity system is highly inadequate and their paddy plants are critically in need of water. The fact that such circumstances occur more often in minor schemes may explain the observation that the use of water for paddy is higher in minor schemes when compared with major schemes, though the percentage of agro-wells in the command area is much higher in the major ones. The percentage distribution of the source of water for pumping, between groundwater from agro-wells and surface water from rivers, canals and tanks, is not far apart between major and minor schemes; groundwater taking about 40 percent and surface water about 60 percent.

FIGURE 6.
Private investments in agro-wells and irrigation pumps in irrigation schemes in the dry zone of Sri Lanka, in 1995 prices, 1965-2000.



The dug-wells are generally shallow, ranging from a minimum of 14 ft to a maximum of 40 ft (table 6). It is interesting to observe that the minimum and the maximum depths are greater in the minor schemes than in the major schemes. Accordingly, the average depth is 22 ft for major schemes and 24 ft for minor schemes. This also suggests that farmers in major schemes generally face better groundwater conditions than those in minor schemes do face. Indeed, the depth or the level of the groundwater table is the most critical factor that determines the economic performance of agro-wells. The cost of digging them depends heavily on the required depth. Throughout the dry zone, it is not rare at all to see abandoned dug-wells; at least, 10 percent of the dug-wells are abandoned or left unused in both major and minor schemes.[31] The reason, more often than not, is the low economic profitability in their use, and the depth of wells is a criterion for profitability.[32]

The estimated private investments on agro-wells and irrigation pumps by farmers are summarized in table 7, and their trends are depicted in figure 6.[33] As in the case of public investments, private investments are expressed in 1995 prices, using the implicit GDP deflator for construction as the deflator.

It is estimated that the total private investment in wells and pumps is about Rs 0.5 billion (in 1995 prices) at present, of which 55 percent is on lined dug-wells and 42 percent is

[31]Abandoned dug-wells are found more in regions with unfavorable groundwater conditions such as in the southern dry zone, but it is not rare to find abandoned wells even in the northwestern dry zone where groundwater conditions are considered most favorable.

[32]Many farmers interviewed maintained that should the depth of groundwater table be more than 30 ft, little chance would exist for an agro-well to be successful. This is in sharp contrast with the fact that there are many wells for domestic water in non-agro-well areas, which are as deep as 100 ft.

[33]Farmers' investments in agro-wells and pumps are estimated simply by assuming standard rates for costs of installing agro-wells and irrigation pumps. The following rates in year 2000 prices are assumed: lined dug-well (diameter = 20 ft, depth = 20 ft) = Rs 81,000; unlined dug-well (diameter = 20 ft, depth = 20 ft) = Rs 6,200; tubewell (diameter=4 inch, depth=24 ft) = Rs 7,000; and pump (2 inch diesel 3.5HP with 2 inch pipe of 200 ft) = Rs 38,400. For more details, see Kikuchi et al. (2001).

TABLE 7.
Private investments in agro-wells and irrigation pumps in irrigation schemes in the dry zone of Sri Lanka, in 1995 prices, 1965-2000.[1]

	Lined dug-well[2]	Unlined dug-well	Tube-well	Irrigation pump	Total
	Investment (Rs million)				
1965	-	-	-	0	0
1970	-	-	-	2	2
1975	0	0	-	19	20
1980	0	0	0	26	26
1985	24	0	0	67	91
1990	158	0	1	159	318
1995	145	3	4	201	353
2000	296	8	7	224	535

[1]Estimated based on the data obtained in our survey. - stands for none, and 0 carries some number below decimal point.

[2]Including subsidy. Assuming 65% of lined dug-wells are subsidized for the amount of Rs 30,000 in 2000 prices, the total amount of subsidy is estimated to be as follows:

1980 Rs 0.1 million (0.2%), 1985 Rs 3.2 million (4%), 1990 Rs 18.6 million (9%), 1995 Rs 32.9 million (10%), and 2000 Rs 58.9 million (12%), where figures in parenthesis are the percentage of subsidy in the total investment on agro-wells and irrigation pumps.

on pumps (table 7). Investments in unlined dug-wells and tubewells are negligible in terms of value, mostly because of their cheap construction costs. The percentage share of the investment on lined dug-wells in total private irrigation investment has been increasing rapidly, exceeding 50 percent in 1997.

It should be noted that the investment series for lined dug-wells in table 7 includes subsidies given to farmers by the government, donor organizations and NGOs, that should be considered as ‘public’ investments. The total amount of the subsidy given to farmers is estimated to be Rs 59 million or 11 percent of the total investment on agro-wells and irrigation pumps in 2000.

The incidence of agro-wells in the dry zone has a relatively short history. The lined dug-well was first reported in 1975 in a survey of major schemes in Kurunegala, and in 1980 in a survey of minor schemes, also in Kurunegala. However, the diffusion of the lined dug-well became significant only in the late 1980s. The tubewell first appeared in 1980 in a minor scheme of the Deduru Oya basin, and later in 1990s in other minor schemes of the basin. The unlined dug-well has an even shorter history of diffusion, starting in the late 1980s.

The use of irrigation pumps has a much longer history than agro-wells. Its adoption by individual farmers in the sample schemes dates back to the mid-1960s, but pumps owned by some agricultural cooperatives were used for irrigation even earlier, in the 1950s. Farmers say that a series of intense drought periods around 1970 triggered the adoption of irrigation pumps. As shown in figure 6, the diffusion of the pump increased toward the mid-1980s, and has been further accelerated since then just as agro-wells have diffused.

It was specially after 1989 when the government commenced the well subsidy program that the investments in agro-wells and pumps rose sharply. The impact of the subsidy program is apparent in figure 6. The investments in agro-wells and pumps showed rapid increases again in the mid-1990s. However, the rate of increase seems to have been declining since then. Such trends have been brought about mainly by the deceleration of the increase in lined dug-wells and pumps.

These findings seem to indicate that the 'initial' diffusion phase wherein the investments increase at an explosive rate is over for lined dug-wells and pumps, and the 'matured' phase is on, wherein the investment is made just to replace abandoned or retired agro-wells and pumps so that their stock is kept constant. If the need for their abandonment or replacement was taken into account, the 'working' stock of lined dug-wells and pumps, would have been found to be increasing only slowly, if not decreasing.[34] In contrast, the diffusion of unlined dug-wells and tubewells appears to be still in its "initial" phase.[35]

How large are the private investments on agro-wells and pumps when compared with the public investments on irrigation? Starting from nearly a negligible percentage share around 1970, the private irrigation investments now take as much as 20 percent of the total irrigation investments (table 1). A reason for the increasing share of private investments in the last decade and a half is the sharp decline in the total investments, due, largely to the decline in the investments in construction of new irrigation schemes. However, the increase in the private investments has indeed been significant. By the mid-1990s, the private investments exceeded the total O&M expenditure for the existing irrigation schemes as a whole.

Rate of Return to Private Irrigation Investments

Changes in cropping pattern with agro-wells and pumps: As observed in table 6, more than 50 percent of agro-wells have been constructed in the highland, and the rest in the command area of irrigation schemes. It is also evident that the main purpose of setting up agro-wells and pumps by farmers is to irrigate OFCs. They use ground water to irrigate paddy only occasionally to supplement surface water.

In major and minor irrigation schemes alike, the cropping pattern in the command area before the adoption of agro-wells and pumps had been simple; either paddy in *maha* and *yala* seasons (major and minor cultivation seasons, respectively) in case surface water is available in both seasons, or paddy in maha and fallow in yala in case surface water is available only in maha season. The only difference between major and minor schemes in this respect was that the cropping intensity was generally higher in major than in minor schemes; on average, 1.4 in major schemes and 1.0 or even less in minor schemes. The cropping intensity of less than 1.0 indicates that surface water is not sufficient to plant paddy in the entire command area even in maha season. There were irrigation schemes where OFCs were planted in yala season, but the extent planted with OFCs was negligible in spite of government efforts to promote crop diversification.

The introduction of agro-wells and pumps has changed this cropping pattern in the command area to one with higher cropping intensity through planting OFCs in the command area hitherto left fallow in yala season. Popular OFCs planted in the command with water from agro-wells are chili, red and big onion, various pulses, banana and many kinds of vegetables such as eggplant, cucumber, okra, bitter gourd,

[34]As mentioned earlier, the abandonment ratio of lined dug-wells is at least 10 percent. Farmers insist that the usable life of an irrigation pump is more than 10 years, often reaching as long as 30 years. Assuming a 15 year life time and straight-line depreciation, the rate of depreciation is 6.6 percent. These rates can be compared to the investment-stock ratio in 2000 of lined dug-wells and of pumps, which is 13 percent and eight percent, respectively.

[35]Considering the rough nature of our estimation, however, further careful studies are required to confirm whether the diffusion of lined dug-wells and pumps has reached the "matured" phase.

brinjals, etc. Paddy is rarely selected as a yala season crop to be irrigated by well water.

Crops grown on the highland part of irrigation schemes differ between major and minor schemes, as the size of highland is different. On the small highland area in major schemes, even from the times before the introduction of agro-wells, farmers have been planting OFCs in maha season, similar to those OFCs they plant in the command in yala season with well water. The much larger tract of highland in minor schemes has typically been planted in maha season with such crops as kurakkan, maize and tobacco, in addition to the OFCs planted in major schemes. It was common in major and minor schemes that almost no cultivation was done on the highland during yala season before the adoption of the agro-well and pump—without irrigation, it is difficult to grow crops in yala season under the climatic conditions of the dry zone. The only exception was gingelly, planted in yala season, only on a small part of the highland, particularly in minor schemes.

With agro-wells and pumps, the cropping pattern in the highland in yala season has changed significantly in both major and minor schemes. Fallow or extensive cultivation with gingelly has been replaced by intensive OFC cultivation in the area irrigated by well water. The area irrigable with a set of well and pump being around 0.20 ha to 0.81 ha, an average major scheme farmer owning an agro-well in the highland may be able to irrigate the entire extent of his highland. By contrast, the cropping intensity in yala season for an average minor scheme farmer may range from 20 percent to 80 percent.[36] The list of OFCs planted with well water in the highland in yala season largely overlaps the list of OFCs in the command area. Certainly, the similarity between the OFCs planted with well water in major schemes and minor schemes, using agro-wells, and across river basins and other regions is remarkable. Of the OFCs irrigated by pumped-up water from agro-wells, rivers, canals and tanks, a few crops are listed in annex table a-7 to depict the irrigation performance.

Cost of well and pump installation: The cost of digging agro-wells varies significantly, depending not only on the type of well but also on the depth of the well, among various other factors. In the following section, we show the costs of well and pump installation in year 2000 prices.[37]

The simplest case is the unlined, open dug-well. It is dug by using a machine shovel (locally called 'bako'). As long as the well is not too deep, the digging is quite easy, taking only a few hours to finish. Unlike a lined one, however, it is necessary to make additional digging or de-silting using a machine shovel every three years or so. It is estimated that the digging cost increases progressively as a well becomes deeper. At the mean depth of 16 ft (4.9 m), the digging cost is estimated to be Rs 6,500. For our cost-benefit analysis, let us assume this level as the construction cost of an unlined well. The additional digging cost per year is assumed to be Rs 580, based on the information obtained from farmers in our survey.

The method to dig a lined dug-well is the same as for an unlined one. After digging by machine shovel, in this case, the wall of the well is trimmed into a cylindrical shape and lined manually, using bricks and cement. In case the depth of the well is beyond the reach of the

[36]In the dry zone, an average farmer in major schemes cultivates 0.97 ha of lowland and 0.16 ha of highland, while an average farmer in minor schemes cultivates 0.48 ha of lowland and 1.05 ha of highland (Kikuchi et al. 2001).

[37]For details, see Kikuchi et al. (2001).

machine shovel, further excavation is done manually, using hoes, shovels and iron stick bars. It is estimated that the digging cost increases progressively as a well becomes deeper, while the lining cost is estimated to be proportional to the depth of the well. With the typical depth of 20 ft (6.1 m), the cost of digging and lining is estimated to be Rs 35,000 and Rs 45,000, respectively, totaling up to Rs 80,000. If the depth becomes 40 ft, the total cost could become as high as Rs 230,000. For cost-benefit analysis, let us assume these levels for lined dug-wells.

A tubewell is installed by using a drilling (boring) machine. The boring cost depends on the diameter of the well as well as the depth. In Kalpitiya, it takes only 2 to 6 hours to drill a tubewell, 6 inch diameter and 25 ft deep, with the total cost of Rs7,700. In the Deduru Oya basin, a tubewell, 4-inch diameter and 24 ft deep, can be installed within a day at a total cost as cheap as Rs 6,600, of which Rs 4,300 is the machine rental for boring and Rs 2,300 is the cost of the 4-inch tube and labor.[38] In the case of tubewells too, the boring cost increases as the depth of the well becomes more, but the rate of cost escalation is much less than in the case of lined dug-well; the boring cost of a tubewell, 60 ft deep, is estimated to be Rs 18,250. In this study, let us assume the installation cost as Rs 6,600 for the typical tubewell, 4-inch diameter and 24 ft deep, and Rs 30,200 for a tubewell, 4-inch diameter and 60 ft deep.

Farmers use pumps of various sizes to lift water from agro-wells, rivers, canals and tanks. The most typical pump is the 2-inch one with a diesel engine of 3 to 4 HP. Let us assume that the 3.5 HP pump costing Rs 32,000 to be the typical pump used by farmers. Operation and maintenance costs of a diesel pump are estimated by assuming a fuel efficiency of 1-hour operation per 1 liter of diesel, and 3 liters of oil per crop season for greasing, with a unit price of Rs 15 and Rs 100 per liter, respectively.[39]

Except when distributing pumped-up water from paddy to paddy, farmers use plastic pipes, usually of 2 inch diameter, for water distribution to their fields. Typically, the total length of the pipe necessary for distributing water from a dug-well to irrigate OFCs in a field of about 0.81 ha is 200 ft, costing Rs 6,400. In the case of lifting water from rivers, canals and tanks, the length of the pipe may have to be much longer. A farmer in the Kirindi Oya basin uses a 2-inch pipe, 1,200 ft long (cost Rs 38,400) to distribute water from the river to his fields.[40]

Rates of return to well and pump investment: Let us assess the rate of return to farmers' investments on various types of agro-well and irrigation pump by estimating the internal rate of return (IRR) that satisfies the formula:

[38]In the Kirindi Oya scheme of the southern dry zone, it costs only Rs 3,900 to install a tubewell, 6 inch diameter and 30 ft deep.

[39]Farmers in Kalpitiya use electric motors of 1.5 to 2 HP for pumping up water from tubewells. It is assumed that the price of a 1.5 HP electric motor is Rs 14,500, and the running cost is Rs 3,000 for electricity (2.5 months of operation).

[40]In Kalpitiya, farmers install underground 2-inch pipe networks to irrigate OFCs in the upland of around 0.81 ha, with a total length of about 200 ft. Including labor for the installation of the network, the total investment on this pipe network amounts to Rs 3,600.

$$C = \Sigma_{i=1}^{n} (R–c) / (1+r)^{i} = (R–c) \{[(1+r)^{n} – 1] / [r (1+r)^{n}]\}$$

Where:

C = investment cost on the well and pump,

R = increase in gross value-added or in farmers' net income due to the investment,

c = operation and maintenance cost of the well/pump,

r = internal rate of return, and

n = the usable life of the well/pump (assumed to be 15 years).[41]

R is estimated by deducting the income (gross-value added = the total output value less the current input costs) accruing from crops grown before the introduction of the well and pump, from the income accruing from new crops after the introduction. Farmers' net income is obtained by deducting capital depreciation of the well and pump, from the farmers' gross income defined as total output value less paid-out costs. The rate of return based on the increase in gross value-added can be considered as the social rate of return, while the rate of return based on increase in farmers' net income is the private rate of return.

Table 8 summarizes the results of estimation that are made for eight different cases. Since water from wells is almost always lifted using pumps, the estimation is made for the investment in a set of an agro-well and pump, except the 7th case of only a pump for water from the river. Both social as well as private rates of return are shown in the table. The investment on the well and pump is made by farmers, and their investment decision depends on the private rate of return to the investment. To the extent that the return to farmers diverges from the return to society, the two rates of return become different. Criteria for judging whether investments on the well and pump are economically viable are therefore different for farmers and society. A criterion popularly adopted for public irrigation investments is whether their IRR exceeds 10 percent, a typical interest rate adopted for public international loans, and thus considered as a measure of opportunity cost to society of such funds for public investments.

First, It should be noted that all the estimated social IRRs in table 8 far exceed this threshold interest rate, which indicates that investments in agro- wells and pumps generate benefits to society, even in the case of the lowest level of IRR. Compared to the IRRs of public irrigation investments in table 4, the social rates of return to farmers' investments on agro-wells and pumps are apparently superior. The social IRRs for private investments, in particular, are definitely higher than the IRR for new irrigation construction investment. In terms of figure 1, curve W representing the investments on agro-wells and pumps is clearly positioned below curve I. Moreover, the social IRRs of well-pump investments considerably exceed the IRRs of major rehabilitation projects. It is impressive that the IRR of the Gal Oya project, the most successful major rehabilitation project of Sri Lanka, or may be of the entire developing world, is nearly at the same level as the lowest social IRR among the cases listed in table 8. Furthermore, farmers' private investments under favorable conditions dominate even the IRRs of very successful water management projects.

High social rates of return, however, do not necessarily mean that the well- pump investments are satisfactorily profitable to farmers. Farmers' investment criteria must be the opportunity cost to them, not to society at large,

[41]Fifteen-year life span of the dug-well, tubewell and the pump may sound too long, particularly for the pump. However, in many cases, farmers have been using irrigation pumps for more than 20 years.

TABLE 8.
Internal rate of return (IRR) for various types of well-pump investment

		Specifications					IRR (%)[1]		
		Well			Pump[2]				
		Lined/ Unlined	Diameter	Depth		Crop[3] grown	Social	Private	With subsidy
1	Dug-well+pump	Lined	20 ft	20 ft[4]	2" diesel 3.5HP	B onion (No. 1)	56	37	49
2	Dug-well+pump	Lined	20 ft	30 ft[4]	2" diesel 3.5HP	B onion (No.1)	24	9	11
3	Dug-well+pump	Unlined	20 ft	16 ft[5]	2" diesel 3.5HP	B onion (No.1)	147	107	-
4	Tube-well+pump	-	4"	24 ft[6]	2" diesel 3.5HP	B onion (No.1)	154	114	-
5	Tube-well+pump	-	5"	60 ft[7]	2" diesel 3.6HP	B onion (No.1)	112	81	-
6	Tube-well+pump	-	4"	24 ft[6]	2" diesel 3.5HP	Rice (No.2)	36	20	-
7	Pump (river-lift)	-	-	-	2" diesel 3.5HP	R onion (No.3)	137	110	-
8	Tube-well+pump	-	6"	25 ft[7]	2" electric 1.5HP	R onion (No.4)	588	460	-

[1] Social rate of return based on gross value added and private rate of return based on increase in farmers' income. 'With subsidy' is the private rate of return with government subsidy for dug-well of Rs 30,000.

[2] Price of pump: Rs 32,000 for Kubota/Robin, and Rs 14,500 for electric motor. Also assume that for cases 1 through 5, 200 ft long 2"plastic pipe (Rs 32/ft except case 7, Rs 13/ft for case 7) is used for water distribution to fields, and 1,200 ft 2"plastic tube (Rs 32/ft) for Case 6. Fuel consumption of a diesel pump is assumed to be 1 l (Rs 15/l) for 1 hr operation, and 4 l of oil (Rs 120/l) are required per season.

[3] For details, see annex table a-7. Number in ( ) refers to the row in appendix table a-7. For cases 1 through 7, assume gingelly (No. 5 in annex table A-7) as the crop grown under the rainefed condition.

[4] The cost of digging and lining of a dug-well is Rs 80,000 for 20 ft and Rs 230,000 for 40 ft.

[5] The digging cost of unlined dug-well: Rs 6,500. Including the cost of 200 ft of 2" pipe for water distribution, the total cost is Rs 12,900. Additional digging cost of Rs 1,750 required every three years is included as a part of operation and maintenance cost.

[6] The digging cost: Rs 13,000, including the cost of 200 ft of 2" pipe for water distribution.

[7] The digging cost: Rs 11,300, including the installation cost of under-ground water distribution system using 200 ft long 2"plastic pipe.

of their investment funds. If farmers mobilize investment funds from their own savings, opportunity cost of the funds might be the interest rate of commercial banks' on saving deposits, which is about 12 percent per year. If farmers have to finance the funds by borrowing from someone, the rate of return from their investment must exceed the interest rate of that borrowing. There are numerous lending sources from government lending institutions, commercial banks and various informal moneylenders—though sources available to farmers are rather limited.

The typical interest rate of development loans for which the government gives concessions is 12 to 20 percent per year. Because of the difficulty in providing collateral, commercial bank loans which require collateral (at interest rates of 15-25 percent per year) are not readily available to farmers. It may neither be too difficult, but not so easy, for farmers to obtain loans without collateral from commercial banks at interest rates of 25 to 35 percent per year. Successful credit cooperatives in rural areas are not so many in number, but, they offer loans to farmers at the interest rate of 2 to 2.5 percent per month, or 27 to 34 percent per year. Informal lending sources are easily accessible to farmers in rural areas, but their interest rates are as high as 5 to 10 percent per month, or 80 to 200 percent per year.[42] Such a setting in rural

[42] It is not rare to find in rural areas, informal loans that are really usurious, with interest rates of 20 percent per month, or 800 percent per year, but these high-interest loans are usually for consumption purposes.

financial markets suggests that the opportunity cost of investment funds to farmers ranges from 12 percent upward. Depending on the financial markets that farmers actually have, the threshold interest rate could be 12, 20, 30, 80 percent, or even higher. Faced with these higher interest rates, these investments are less attractive to farmers than for society at large.

In table 8, the first two cases refer to the investment in a lined dug-well and pump. The difference between the two cases lies in the depth of the well—20 ft for case 1, and 40 ft for case 2. For the lined dug-well 20 ft deep, the private IRR is 37 percent, lower than the social IRR by 20 percent. Even if the high risk inherent in the well investment and in OFC cultivation is taken into consideration, it could be said that this level of rate of return to farmers is sufficiently high to make repayment on loans without collateral extended from commercial banks possible. If we take into account the subsidy given for the lined dug-well of Rs 30,000,[43] the private IRR increases to nearly 50 percent. The depth of the great majority of lined dug-wells is 20 ft or less, which means that the private IRR with subsidy is higher than this level in many cases. Such decently high rates of return to farmers explain the great proliferation of lined dug-wells in the Northwestern part of the dry zone in the last decade.

As mentioned earlier, however, the cost of digging a lined dug-well increases progressively as it becomes deeper. This means that the economic viability of lined dug-wells decreases quickly as it becomes deeper. If the depth of a dug-well is 40 ft, the social IRR decreases to 24 percent and the private IRR to 9 percent. The investment is still economically viable to society, but the incentive for farmers to make this investment is lost. The subsidy recovers the private rate of return only at 11 percent, which is below the threshold level of 12 percent. With high risks associated with well investments and OFC cultivation, this level of private profitability would scarcely warrant investing in this opportunity. It should be mentioned that the benefit of dug-wells and pumps is estimated for cases with very favorable groundwater conditions. For less favorable cases, the economic performance of this well-pump investment could be far less than the level assumed here. In such cases, even the economic viability to society could easily be lost.

Such findings are consistent with our observation that there is no lined dug-well deeper than 40 ft, and that there are many lined dug-wells left unused. At least one out of ten lined dug-wells in the dry zone, including the northwestern part of the dry zone, are in an abandoned state, and in some irrigation schemes 50 percent to 100 percent of wells are unused. On the other hand, the number of lined dug-wells has been increasing. These incidences suggest that, while investments in the lined dug-well can attain a decent level of rate of return in areas with favorable groundwater conditions, there are many other areas where the use of lined dug-wells is not economically feasible, socially or privately. The relatively low level of economic performance of the lined dug-well and pump thus underlies the observation that the "initial" diffusion phase of the lined dug-well and pump was over, giving in to the "matured" phase.

Case 3 in table 8 refers to the unlined dug-well with pump, typically found in some parts of Mahaweli system H and some other major irrigation schemes in the Kala Oya basin, and case 4, to the tubewell with pump, typically found in minor irrigation schemes in the Deduru Oya basin. The investment in the well and pump in these cases is highly profitable; not only the social IRRs but also the private IRRs are more

[43]The government subsidy per lined dug-well since 1999. It was Rs 15,000 for 1989-91 and Rs 20,000 for 1992-98.

than 100 percent. Case 5 shows that the private IRR is still as high as 81 percent for a tubewell 60 ft deep. Even if the risks are taken into account, these levels of private IRRs would be sufficient to induce farmers who have only the informal money market to invest in the well and pump. Such high rates of return to farmers have been behind the rapid diffusion of unlined dug-wells and tubewells in the northwestern part of the dry zone entirely on the farmers' initiative and with no government intervention.

It is interesting to observe that case 6, which is same as case 4, except that the crop grown is paddy, gives results greatly inferior to those of case 4. Similar results are obtained, if estimated for the case of the unlined dug-well with rice as the crop to be grown. It should be noted that the level of the rice yield assumed in this estimation is 5.2 t per hectare (100 bushels per acre), which is about 50 percent higher than the average yield in minor irrigation schemes, or 10 percent higher than the technology level NIV N=140 assumed for the public irrigation investment cases.[44] Even with such a high yield level, the IRRs are far less impressive than those with high-value OFCs. Such estimation results are due partly to the low paddy price at present, and also the heavy water requirement for paddy cultivation. As the possibility of conjunctive use of well and surface water becomes less, the IRR for rice declines quickly. This is the main factor that underlies the fact that the overwhelming majority of farmers use the well-pump water for OFC cultivation rather than for rice cultivation.

Case 7 examines the economic performance of the pump as used for lifting water from rivers, canals and tanks for OFC cultivation. Investment costs being cheap, the private IRR is high enough to induce farmers' investment. As long as a sufficient amount of water is available within a reasonable distance for pumping up, farmers would always be tempted to invest in the pump.

The final case is for the tubewell and the power-operated pump in Kalpitiya, Puttalam. On the one hand, investment and running costs, including the well digging, the electric motor and electricity for operation, are the cheapest among the cases examined in table 8. On the other hand, plentiful groundwater supplied from the shallow coastal sand aquifers in the area (Panabokke u.d.) enables farmers to grow high value-added OFCs such as red onion, three times a year, with a high income. The combined result is extremely high rates of return on the investment.[45,46]

Future Prospects

The private rates of return to the investments on agro-wells and pumps are thus sufficiently high to induce farmers' to invest, even if high opportunity costs to farmers are taken into account, except in the case of very deep lined dug-wells. The high social profitability of the well-pump investments is therefore realized through private investments that characterize phase III of irrigated agriculture development.

[44]This 10 percent yield margin may be considered as the yield-enhancing effect of conjunctive water use for rice production.

[45]It should be noted that in the Kalpitiya case, only one-third of the gross value-added or income is taken into account as the return to the investment on the tubewell and electric pump, with the rest two-thirds assumed to be foregone. Should there be no foregone income, the private IRR of the investment on the tubewell and electric pump in Kalpitiya would exceed 1000 percent with a wide margin.

[46]As far as we observed in our survey, the use of electricity as the source of power for lifting water in the dry zone is confined to Kalpitiya. This virtual nonexistence of the electricity-operated pump in irrigation schemes in the dry zone of Sri Lanka is in sharp contrast to the situation in India where the use of electricity, which is heavily subsidized by the government, has facilitated the diffusion of agro-wells and pumps considerably in the last two decades (Shah 1993).

The investments on the unlined dug-well, the tubewell and the pump to lift surface water generate very high private rates of return. The estimates suggest that these devices have profound prospects for further diffusion. The diffusion of the lined dug-well that has the lowest rate of return out of the three types of agro-wells, would continue, but only in areas with favorable groundwater conditions that allow the depth to be as shallow as 20 ft or even less. Unlined-dug-wells and tubewells, on account of their high performance which can replace lined dug-wells, will become the dominant types of agro-well even in areas with favorable groundwater conditions. In particular, it is the tubewell that would have the highest potential for future diffusion, because of its low boring cost even with deeper aquifers.

A distinct feature of agro-wells in Sri Lanka when compared to other South Asian counterparts is their shallowness resulting in the use of small-sized pumps and thus, the small size of the irrigable area for a set of an agro-well and a pump. This may be related to groundwater conditions set by the topographical and hydrological conditions specific to the dry zone of Sri Lanka. In any case, groundwater aquifers from which agro-wells get water are closely associated with the flow of surface water along respective river basins and within respective irrigation schemes. To the extent that these two sources of water are related to each other, the conjunctive use of surface and groundwater would increase the need for integrated management of the water sources for irrigated agriculture to be sustainable. Unlike in other South Asian countries, there have hitherto been few reports that agro-well development leads to the overt depletion of groundwater. For the conjunctive use of water to be efficient and equitable, however, the basin-wide joint management of and control over surface and groundwater would become increasingly necessary.

It should be noted in this connection that the proliferation of agro-wells and pumps that give farmers more discretion over water use would enhance their individualistic behavior. However, the promotion of farmers' involvement in O&M of irrigation schemes, by fostering their organizations, through their cooperation and collective action, has been a state policy. Striking a good balance between these two opposite vectors for the development of irrigated agriculture would be an important policy issue in the future.

Concluding Remarks

The total investment in the irrigation sector in Sri Lanka had been declining sharply since the early 1980s toward the mid-1990s. Within this period of a decade and half, the total investment has shrunk in real terms to a level that is one fifth of the peak level in the early 1980s. Since there had been no private irrigation investment until the mid-1990s, the decline in the total irrigation investment is due to the decline in public irrigation investment. Out of the three types of public investment, new irrigation construction has recorded the sharpest decline. Although the percentage share of rehabilitation investment in the total irrigation investment has increased, its absolute amount had declined since the mid-1980s up to the mid-1990s. The O&M expenditures were stagnant in the last two decades, or even declining since the mid-1980s. For the total irrigated area that had increased by 25 percent or by 0.1 million hectare during this period, the O&M expenditures per ha of irrigated area declined considerably.

In the last half decade, the total irrigation investment has shown a slight upward trend from the low the irrigation sector had reached in the early 1990s. However, the relative composition of investments is entirely different from what existed before the early 1990s. Investment in irrigation rehabilitation has increased and taken the largest share in the total irrigation investment, while investment on new irrigation construction has continued to shrink and given the top-share position to irrigation rehabilitation for the first time in the history of the irrigation sector. Also remarkable are the rapid increases in private irrigation investment. The investment on agro-wells and irrigation pumps by farmers was negligible until the end of the 1980s, but was increasing rapidly in the 1990s, exceeding the O&M expenditure for the entire major irrigation schemes by a wide margin.

The estimation of the rates of return to public irrigation investments reconfirms that phase II of the development in irrigated agriculture, that is, the phase of new irrigation construction by the public sector, was over by the early 1980s in Sri Lanka. The sharp decline in investment in new irrigation construction has been brought about by the drastic drop in the profitability of this type of investment. The sharply rising cost of new irrigation construction in real terms has been a major factor that choked off the incentive to invest in new irrigation construction. The low rice price since the collapse of the commodity boom in the mid-1980s certainly encouraged the government and international donor agencies to shy away from the investment in new irrigation construction. Though very drastic, the reduction in new construction investment is what is expected to occur once phase II is over.

During the entire phase II, irrigation systems were administered, not managed. The entry into phase III signals the higher profitability for investment in management and control of water deliveries and therefore greater emphasis on software as opposed to hardware. High profitability of some major rehabilitation and water management improvement projects implemented in the 1980s attests that the irrigation sector has been in phase III, that is, the phase of rehabilitation and water management. But, some other projects of this type have revealed economic performance that is far less than expected. Such results suggest that deliberate project design and implementation with due attention to software and institutional focus are a prerequisite for this type of irrigation project—if they are to realize their economic potential. In particular for major rehabilitation projects, there is a strong need to develop more cost-effective methods/approaches of improving physical structures in order to reduce the unit capital cost.

Poor performance seems to have been one of the factors leading to a decline in investment in rehabilitation projects toward the mid-1990s. This is not a trend that we expect to observe in phase III, and indeed this declining trend has been reversed in the last half decade. A rough estimation of the investment needs for rehabilitation indicates that the rate of under-investment in this respect is 25 percent at present, but the rate of under-investment was as high as 60 percent in the early 1990s.

More serious is the declining trend of O&M intensity. The negligence of and under-investment in O&M have been a chronic problem ever since the irrigation sector entered the phase of new constructions. In the phase of water management, this problem had become rather less serious—O&M intensity has recently been declining even beyond the level attained in 1980 when the irrigation sector was at the peak of new constructions. In spite of the very high rate of return on adequate O&M, the rate of under-investment is estimated to be 60 percent at present. Considering the difficulties in implementing effective O&M, the degree of under-investment at the system level could be even more serious than this estimate indicates.

Discrepancies between the potentially high profitability and the trends in public investments actually realized for rehabilitation and O&M in phase III indicate a compelling need to improve the way rehabilitation projects and O&M activities are designed and implemented. Cost-effective methods for system rehabilitation and O&M with improvements in physical/ engineering as well as institutional aspects must be pursued. Most important among others would be to establish an effective incentive system that ensures the realization of large potential benefits of rehabilitation/modernization projects, and particularly, of adequate O&M.[47] The Sri Lankan government is seeking to achieve this through greater involvement of user groups in O&M, but the impact of the program to date has been modest (Samad and Vermillion 1999).

Many other rice-growing countries in Asia face the same problems due to low rice prices and rising construction costs. The gradual deterioration of the existing irrigation schemes, which is an inevitable result under this situation, may precipitate conditions for a food crisis in the near future. The sudden rise of world rice price due to such crises would call for funds to the irrigation sector for crash projects. But, we have already seen many crash irrigation projects accompanied by unnecessary waste in the decade following the food crises in the 1970s.

Meanwhile, the poor performance and gradual deterioration of existing irrigation schemes have spurred a revolution in groundwater development. An increasing number of farmers have been installing agro-wells and irrigation pumps in the command and the highland; it is estimated that about 10 percent of farmers in irrigation schemes own agro-wells and about 15 percent, irrigation pumps. High rates of return, socially as well as privately, on investments in agro-wells and pumps have encouraged their rapid diffusion, making the private investments as major options in phase III of irrigated agriculture. Large potentials exist for further diffusion of agro-wells and pumps in irrigation schemes.

Agro-wells and pumps give farmers more discretion over water use, promote diversification to high-value crops, and thereby increase farmers' income. The diffusion of well-pumps has had a positive impact. Productivity improvements in the irrigation sector, expected in phase III of irrigated agriculture development, have been attained largely by private irrigation investments in agro-wells and irrigation pumps, and not by public irrigation investments/expenditures. But one needs to be cautious of being overly optimistic of the beneficial effects of agro-wells. The current analysis shows that under prevailing conditions, the returns on investments in agro-wells are sufficiently high to attract private investments in this sector. However, future events may change the incentive structure. Investments in agro-wells are almost exclusively for OFC cultivation. At present, due to civil unrest, only limited amounts of OFC cultivated in the Northern Province, especially the Jaffna peninsula —a traditional area producing other field crops—enter the local market. With the return of peace, there is a strong likelihood of OFCs produced in the North entering a saturated market and thereby depressing their prices. Furthermore, there is the likelihood of cheap imports of competing crops from India under the South Asia Free Trade Agreement (SAFTA), if it becomes effective. Unless there is a major change in the portfolio of crops grown under agro-wells, these events could affect new investment in agro-wells and curtail the diffusion of agrowells.

[47]It is difficult to institute an effective incentive system by which the potential benefits can be internalized. Breaking the vicious circle between deferred maintenance (negligence of O&M) and early rehabilitation, cost sharing by beneficiaries of rehabilitation projects, and performance-linked subsidy for O&M by beneficiaries are some examples of many possibilities.

The shallowness of agro-wells is a salient feature of the agro-well "revolution" in Sri Lanka, which suggests that groundwater aquifers are closely associated with the flow of surface water in river basins and irrigation schemes. To the extent that these two water sources are related to each other, the conjunctive use of surface and groundwater would demand integrated management of the water sources, for irrigated agriculture to be sustainable. Unlike in other South Asian countries, there have thus far been few reports that agro-well development leads to the overt depletion of groundwater. No institutional coordination between surface water and groundwater development has hitherto existed, and the largely unregulated installation of private agro-wells could lead to over-exploitation and increased pollution, as has been the case in many parts of Asia. For the conjunctive use of water to be efficient and equitable, the basin-wide joint management of and control of surface and groundwater would become increasingly necessary.

Development of irrigation in phase III in Sri Lanka should involve a two pronged approach. First, the government should vigorously pursue its plans to devolve greater responsibility for O&M on user groups, while providing sufficient resources. This process of farmers' greater involvement in O&M and other management aspects of irrigation schemes have to be in harmony with the agro-well "revolution" that is essentially the work of the individual farmer. It would be one of the most important challenges for the irrigation sector to find out feasible ways for the integrated management of surface and groundwater at the system level. Second, the government must adopt new policies and develop new institutional mechanisms for allocating water between agricultural and non-agricultural use at the river basin level and also for regulating basin-level development of surface and groundwater irrigation at a macro-level. These steps are required to achieve higher productivity and sustainability of irrigated agriculture, assuring that irrigation remains the backbone of rural and agricultural development in the future too, just as it has been in the past.[48]

[48]Phase III in Sri Lanka coincides with the attainment of self-sufficiency in rice. At this stage of development, the pressure is mounting for the rice sector of the country to be competitive in the world rice market (Barker and Samad 1999). In order to sustain the sector, it is required to increase the productivity of rice production rather than the total rice production at a sufficiently rapid rate, It is the irrigation sector that takes the brunt in attaining this target.

Annex A—Basic Data

Annex table a-1.
Domestic production, Imports, and domestic and import price of rice, 1949-97, Sri Lanka.

	Rice production[a] 1000 mt (1)	Rice import[b] 1000 mt (2)	Self-sufficiency in rice % (1)/((1)+(2))	Price of rice[c] Domestic price Rs/mt (3)	World price[d] Rs/mt (4)
1949	317	602	34		433
1950	303	744	29		422
1951	459	600	43		445
1952	603	606	50		616
1953	457	612	43	680	604
1954	649	601	52	560	525
1955	745	575	56	540	445
1956	561	734	43	550	411
1957	653	781	46	540	376
1958	764	720	51	550	376
1959	759	871	47	550	365
1960	897	789	53	550	354
1961	899	700	56	550	354
1962	1,001	613	62	510	365
1963	1,026	602	63	510	365
1964	1,054	983	52	510	376
1965	757	419	64	540	399
1966	953	1,035	48	529	408
1967	1,145	511	69	652	570
1968	1,346	552	71	760	691
1969	1,374	461	75	729	583
1970	1,616	716	69	712	462
1971	1,396	440	76	693	354
1972	1,312	446	75	712	390
1973	1,312	507	72	1,162	575
1974	1,602	444	78	1,975	1,762
1975	1,154	693	62	2,005	1,325
1976	1,253	563	69	1,791	1,148
1977	1,676	803	68	1,688	1,289
1978	1,890	278	87	1,952	3,106
1979	1,917	315	86	2,014	2,880
1980	2,133	251	89	2,455	3,936
1981	2,229	250	90	3,229	5,008
1982	2,155	259	89	3,407	3,254
1983	2,483	219	92	3,542	3,556

Continued

Annex table a-1, continued.

	Rice production[a] 1000 mt (1)	Rice import[b] 1000 mt (2)	Self-sufficiency in rice % (1)/((1)+(2))	Price of rice[c] Domestic price Rs/mt (3)	World price[d] Rs/mt (4)
1984	2,420	57	98	3,600	3,681
1985	2,661	314	89	3,900	3,392
1986	2,586	344	88	3,960	3,220
1987	2,128	168	93	4,160	3,797
1988	2,477	313	89	4,250	4,937
1989	2,064	471	81	5,660	6,478
1990	2,538	256	91	7,330	6,171
1991	2,389	198	92	7,230	6,228
1992	2,340	353	87	8,060	6,373
1993	2,570	311	89	8,200	6,775
1994	2,684	86	97	7,980	8,844
1995	2,810	13	100	7,760	8,078
1996	2,062	508	80	10,525	9,107
1997	2,239	456	83	9,016	8,425
1998	2,692	250	91		9,226
1999	2,868	319	90		8,284

a) In rough rice.
b) In rough rice equivalent.
c) Farm-gate price of rough rice or rough rice equivalent.
d) The price of Thai 25% broken converted to rough rice at the farm-gate in Sri Lanka.

Sources: (1) For 1949-89, Aluwihare and Kikuchi (1991); for 1990-97, Central Bank of Sri Lanka, Review of Economy, various issues.
(2) Central Bank of Sri Lanka, Review of Economy, various issues.
(3) For 1953-65, IRRI, World Rice Statistics; for 1966-95, FAOSTAT; for 1996-97, DA's Cost of Cultivation of Agricultural Crops.
(4) Kikuchi et al. (2002).

Annex table a-2.
Fertilizer use, nitrogen price and modern variety ratio, 1950-97, Sri Lanka

	Fertilizer[a]					Modern variety ratio[d]		
	Total fertilizer consumption	Fertilizer for rice	Fertilizer use per unit area sown[b]	Nitrogen price		Old improved	New improved varieties	Total varieties
				Domestic farm-gate price	Farm-gate equivalent world price[c]			
	1,000 mt	1,000 mt	kg/ha	Rs/kg	Rs/kg	%	%	%
	(1)	(2)		(3)	(4)	(4)	(5)	(6)
1950	31	0.3	1	na	na	0	0	0
1951	33	0.6	1	na	na	0	0	0
1952	29	0.8	2	na	na	0	0	0
1953	45	1.7	4	na	na	0	0	0
1954	48	2.3	5	na	na	0	0	0
1955	53	3.0	6	na	na	0	0	0
1956	81	5.3	11	na	na	0	0	0
1957	50	3.8	8	na	na	0	0	0
1958	47	4.0	7	1.95	na	2	0	2
1959	68	7.4	14	1.53	na	7	0	7
1960	70	5.5	9	1.20	na	15	0	15
1961	75	7.7	13	0.62	1.5	18	0	18
1962	79	10.2	16	0.61	1.5	22	0	22
1963	84	12.2	19	0.64	1.2	30	0	30
1964	92	15.8	29	0.76	1.5	41	0	41
1965	87	11.4	19	0.93	1.6	42	0	42
1966	91	13.9	21	0.88	1.5	48	0	48
1968	107	24.5	35	0.94	1.4	60	2	62
1969	102	29.2	42	0.89	1.1	67	4	71
1970	105	31.9	42	0.89	1.0	62	9	71
1971	112	38.8	54	0.89	0.9	54	12	66
1972	100	38.8	54	0.97	1.2	51	18	69
1973	111	53.1	73	1.17	2.1	34	39	73
1974	110	42.9	53	2.23	7.3	25	55	80
1975	72	22.7	33	4.40	4.8	32	49	81
1976	95	33.3	46	2.19	3.3	22	60	82
1977	112	54.6	66	3.86	3.9	21	63	84
1978	140	61.5	71	2.90	7.8	22	63	85
1979	137	58.3	69	2.13	9.3	18	65	83
1980	169	84.9	100	4.65	12.7	15	69	84
1981	144	70.5	80	4.65	14.3	13	74	87
1982	155	77.1	91	6.05	11.4	9	89	98
1983	162	74.9	91	6.20	11.0	7	92	99
1984	188	86.6	87	6.62	15.0	6	93	99
1985	195	94.6	107	6.62	12.7	6	93	99
1986	200	108.9	122	6.80	10.3	5	86	91

Continued

Annex table a-2, continued.

	Fertilizer[a]					Modern variety ratio[d]		
	Total fertilizer consumption	Fertilizer for rice	Fertilizer use per unit area sown[b]	Nitrogen price: Domestic farm-gate price	Nitrogen price: Farm-gate equivalent world price[c]	Old improved	New improved varieties	Total varieties
	1,000 mt	1,000 mt	kg/ha	Rs/kg	Rs/kg	%	%	%
	(1)	(2)		(3)	(4)	(4)	(5)	(6)
1987	207	101.7	130	6.58	11.9	5	85	90
1988	207	104.2	120	6.06	17.0	3	82	85
1989	205	111.0	153	6.54	16.4	3	87	90
1990	171	75.7	88	7.55	21.7	3	89	92
1991	177	81.6	100	16.53	24.6	1	49	50
1992	184	93.8	117	20.91	20.0	0	31	31
1993	213	110.5	132	21.50	18.9	1	90	92
1994	214	122.5	132	21.41	20.5	3	90	92
1995	207	118.5	130	19.78	27.6	2	97	99
1996	211	109.8	147	21.78	32.8	1	97	99
1997	219	111.6	153	23.41	27.0	1	98	99
1998	234	117.4	138	22.46		1	99	100
1999				15.22		2	97	99

a) Total nutrients (N+P+K).
b) Total nutrients used for rice divided by area planted with rice.
c) Estimated from the world price of Urea (FOB in Europe) assuming 28% of freight and insurance between the port of origin and the Colombo Port and 25% of margin for transport and handling between the Colombo port and the farm-gate.
d) Ratio of area planted with modern varieties to total area planted with rice.

Sources: (1) and (2) IRRI and National Fertilizer Secretariat, The Review of Fertilizer, various issues.
(3) IRRI and Central Bank of Sri Lanka, Economic and Social Statistics of Sri Lanka, various issues.
(4) Basic data for 1961-95 from IRRI (1995) and for 1996-97 from Central Bank of Sri Lanka, Annual Report 1997.
(5)-(7) Rice Breeding Center of the Department of Agriculture.

Annex table a-3.

Public irrigation investments by type of investment and the GDP implicit deflator for construction, 1948-96, Sri Lanka.[a]

	Current prices				GDP deflator	1995 constant prices			
	New con-struction	Rehabili-tation	O&M	Total		New con-struction	Rehabili-tation	O&M	Total
	Rs million				1995 = 100	Rs million			
1948	16.1	0	2.0	18.1	0.022	734	0	93	827
1949	40.7	0	2.1	42.8	0.022	1,859	0	97	1,956
1950	60.1	0	2.0	62.1	0.023	2,571	0	86	2,656
1951	72.9	0	2.1	75.1	0.024	3,041	0	89	3,130
1952	101.3	0	2.5	103.7	0.024	4,144	0	102	4,246
1953	76.3	0	2.2	78.5	0.024	3,133	0	89	3,223
1954	47.6	0	2.4	50.0	0.024	1,965	0	98	2,063
1955	60.0	0	2.5	62.5	0.024	2,489	0	103	2,592
1956	50.8	0	3.0	53.8	0.024	2,159	0	127	2,287
1957	53.0	0	2.8	55.8	0.026	2,043	0	109	2,152
1958	42.0	0	3.0	45.0	0.027	1,566	0	110	1,676
1959	41.8	0	17.2	59.0	0.026	1,627	0	670	2,297
1960	32.8	0	10.0	42.8	0.026	1,270	0	386	1,656
1961	46.0	0	6.2	52.2	0.027	1,726	0	232	1,958
1962	41.2	0	5.0	46.2	0.027	1,524	0	185	1,708
1963	25.5	0	4.5	30.1	0.027	949	0	169	1,117
1964	33.0	0	5.0	37.9	0.028	1,188	0	178	1,366
1965	47.2	0	5.2	52.4	0.028	1,703	0	187	1,890
1966	40.2	0	3.6	43.8	0.028	1,445	0	131	1,576
1967	73.8	0	3.8	77.6	0.028	2,655	0	137	2,793
1968	83.0	0	4.4	87.4	0.029	2,834	0	152	2,986
1969	91.3	0	5.5	96.8	0.032	2,857	0	172	3,030
1970	91.7	0	5.6	97.3	0.033	2,769	0	169	2,938
1971	75.8	0	6.4	82.2	0.035	2,160	0	181	2,340
1972	77.0	0	11.7	88.7	0.036	2,128	0	325	2,453
1973	134.0	0	12.7	146.7	0.040	3,357	0	318	3,674
1974	104.8	0	14.7	119.5	0.047	2,230	0	312	2,542
1975	155.8	0	17.4	173.2	0.052	2,999	0	336	3,335
1976	175.9	0.4	17.7	194.0	0.056	3,126	7	315	3,448
1977	158.0	3.8	21.3	183.1	0.061	2,607	63	351	3,021
1978	387.2	11.3	22.8	421.2	0.082	4,725	138	278	5,140
1979	726.1	19.3	42.4	787.8	0.111	6,543	173	382	7,098
1980	987.1	59.9	70.8	1117.9	0.172	5,724	347	411	6,482
1981	2,269.5	312.4	78.3	2,660.2	0.224	10,124	1,394	349	11,867
1982	3,034.0	218.5	89.3	3,341.7	0.260	11,663	840	343	12,846
1983	2,928.7	332.5	110.5	3,371.7	0.317	9,229	1,048	348	10,625
1984	2,842.7	266.3	142.7	3,251.7	0.362	7,849	735	394	8,978
1985	2,766.3	412.9	138.3	3,317.5	0.375	7,373	1,100	369	8,842
1986	2,100.9	524.3	169.1	2,794.3	0.390	5,391	1,345	434	7,170
1987	2,312.1	634.5	177.1	3,123.6	0.406	5,692	1,562	436	7,690

Continued

Annex table a-3, continued.

	Current prices				GDP deflator	1995 constant prices			
	New construction	Rehabilitation	O&M	Total		New construction	Rehabilitation	O&M	Total
	Rs million				1995=100	Rs million			
1988	1,600.8	322.3	130.7	2,053.9	0.459	3,485	702	285	4,472
1989	1,009.4	288.9	174.5	1,472.8	0.530	1,906	546	330	2,781
1990	522.9	341.3	149.3	1,013.6	0.640	818	534	233	1,585
1991	684.9	207.5	167.7	1,060.1	0.707	969	294	237	1,500
1992	1,120.2	384.4	189.3	1,693.9	0.759	1,476	507	249	2,232
1993	968.3	306.9	276.1	1,551.2	0.816	1,187	376	338	1,901
1994	561.8	441.2	248.0	1,251.0	0.904	621	488	274	1,383
1995	528.0	382.5	302.0	1,212.5	1.000	528	383	302	1,212
1996	477.7	772.0	308.1	1,557.7	1.122	426	688	275	1,388
1997	848.0	1,376	273.0	2,497.0	1.220	695	1,128	224	2,047
1998	977.5	2,048	314.9	3,340.2	1.322	739	1,549	238	2,526
1999	990.5	1,179	333.2	2,503.0	1.380	718	854	241	1,813

Note: For a compilation of data sources, see Aluwihare and Kikuchi 1991).

Annex table a-4.
Selected new irrigation construction projects used in the cost-benefit analysis.

Schemes	Year com menced	Construction com-pleted	Year settlement com-menced	Com-mand area[a]	Average gestation period[b]	Construction (current prices)	Cost[c] (1995 constant prices)
				ha		years	Rs 1000/ha
Muhathan Kulam	52	57	54	324	4.5	0.93	38.5
Dewahuwa	47	58	49	946	9.6	3.28	135.0
Huruluwewa	49	59	52	3,515	6.8	2.73	100.8
Katupotha	53	59	55	202	5.2	7.92	294.0
Kandalama Tank	52	60	55	842	6.3	5.11	197.8
Periya Madu	52	60	56	304	5.4	3.29	125.5
Chemamadu	54	60	57	243	3.8	1.24	53.1
Parakrama Samudra	46	61	50	7,368	11.0	1.47	58.8
Badagiriya	52	61	57	486	6.0	3.29	121.9
Hattota Amuna	52	61	58	202	5.9	2.97	111.1
Thannimurappu	52	61	56	957	5.5	1.96	52.3
Horiwila	54	61	57	206	5.6	0.97	41.3
Mapakada Wewa	52	62	55	374	6.0	6.95	265.3
Akkarayan Kulam	52	62	62	1,215	6.1	1.40	5.4
Handapangala Wewa	53	62	57	405	5.6	2.96	113.4
Kalmadu Kulam	53	62	57	182	6.0	1.65	57.2
Mahawillachciya	55	62	55	1,079	5.3	4.82	182.2
Gal Oya	49	65	52	37,760	12.0	3.82	148.8
Diul Wewa	53	65	58	162	7.6	3.09	103.7
Pavatkulam	58	65	57	1,674	8.4	3.58	136.2
Usgala Siyambalngamuwa	56	65	58	636	5.8	4.87	177.3
Mahakandarawa	57	65	61	2,429	4.6	3.75	142.9
Mora Wewa	56	65	60	1,215	4.9	3.46	130.3
Karawita Yoda Ela	56	66	60	444	6.9	2.93	109.0
Ettimole Wewa	56	66	57	405	6.0	6.17	228.6
Padaviya	53	67	57	5,263	9.4	3.00	114.2
Kimbulwana	53	67	55	560	10.6	2.68	100.1
Vavunikulam	54	67	59	2,429	8.3	2.31	86.2
Hakwatuna	56	67	62	1,741	6.0	4.71	177.6
Kaudulla	59	67	66	1,862	6.4	3.17	121.1
Kurai	57	69	62	215	7.6	3.26	121.1
Mahatotilla	60	69	64	283	6.5	2.47	90.1
Muthuiyankaddu Kulama	58	70	68	2,429	4.7	3.95	123.9
Visvamadukulam	60	71	64	327	4.8	4.89	157.5
Ambelaperumal	60	72	65	252	6.4	6.35	212.2
Koddal Kaddina	61	72	65	162	6.9	3.09	97.0
Kariyali Nagapanduwa	60	72	63	608	7.8	3.78	130.9
Vdayarkaddu Kulam	63	73	63	486	6.8	2.88	96.5
Muruthawela	67	73	68	1,310	4.2	10.99	332.0
Rajangana	57	73	57	5,523	8.8	5.81	203.2
Nagadeepa	67	73	68	1,619	4.4	8.34	256.3
Pimburattawa	69	75	68	1,619	4.2	7.60	141.1
Wahalkada	73	79	74	810	4.2	24.07	362.0

Continued

Annex table a-4, continued.

Schemes	Year commenced	Construction completed	Year settlement commenced	Command area[a]	Average gestation period[b]	Construction (current prices)	Cost[c] (1995 constant prices)
				ha		years	Rs 1000/ha
Uda Walawe	64	81	64	17,600	12.0	11.85	334.8
Mahadivulwewa	76	82	80	486	3.6	69.14	484.7
Muthukandiya	79	83	80	810	4.2	76.30	462.1
Inginimitiya	79	87	81	2,644	5.1	130.41	433.1
Kirindioya Phase 1	78	88	86	8,951	5.9	142.22	472.4
Mahaweli C (Zone 1-2)	78	90	80	7,300	6.0	172.35	515.0
Mahaweli C (Zone 3-6)	82	94	83	17,700	8.1	342.81	709.9

a) The command area just after the completion of the projects.

b) Average gestation period of the capital investments obtained as the weighted average of gestation years of the investments in each year during the construction period, using the value of the investment in constant prices as weights.

c) Include capital expenditures related to irrigation infrastructure development. Costs related to settlement, supervision and general admin istration are, in principle, not included.

Sources: See Aluwihare and Kikuchi (1991), except for Mahaweli C (Zone 3-6), for which data are from World Bank 1993.

Annex table a-5.

Parameters and assumptions in the cost-benefit analysis for major and minor rehabilitation projects.[a]

	Year project: com-menced	Year project: com-pleted	Year project: benefit start accruing	Total benefited area	Average gestation period	Unit capital cost in: current prices	Unit capital cost in: 1995 prices	Post-project rice yield	Increase in rice yield due to project	Increase in cropping intensity	O&M in 1995 prices
				ha	years	Rs 1,000/ha	kg/ha	kg/ha			Rs/ha
I. Major rehabilitation projects											
TIMP	76	84	83	12,753	4.0	22.57	131.06	4000[b]	471[e]	0.54	1830[i]
Gal Oya	80	87	85	25,000	3.1	18.01	59.84	4000[c]	471[f]	0.59[h]	1830[i]
VIRP	81	90	82	45,555	3.9	20.27	64.69	3000[d]	420[g]	0.08[d]	940[j]
ISMP	87	92	89	70,668	2.5	20.94	38.00	4000[d]	471[e]	0.11	1830[i]
MIRP	85	94	86	23,817	4.4	42.51	85.57	4000[d]	471[e]	0.20[d]	1830[i]
NIRP	91	99	92	38,390	2.2	65.83	57.23	4000[d]	420[g]	0.06	940[j]
II. Water management improvement projects[k]											
Kimbulwana	79	80	80	666	1.5	1.50	11.09	3200	448	0.45	1830[j]
Pimburettawa	86	89	89	2,153	0.5	na	14.46	3100	0	0.64	1830[j]
Nagadeepa	86	89	89	2,640	0.5	na	3.12	2700	0	0.05	0

[a] A common assumption for all the projects is the price of rough rice in 1995 of Rs 8.70/kg. The value-added ratio of rice production is assumed to be 0.8. The usable life time is assumed to be 25 years for the major rehabilitation projects and 15 years for the water management improvement projects except for the Nagadeepa Project for which 2-year life span is assumed.

[b] Assumed to be the same as for MIRP.

[c] Average yield of major irrigation regime in Ampara District for 1983-97.

[d] Based on the Project Completion Report.

[e] Assumed to be the same as for the Gal Oya Project.

[f] 12% of yield increase due to an improvement in water distribution after the project is assumed as in Aluwihare and Kikuchi (1991).

[g] 14% of yield increase due to an improvement in water distribution is assumed as in the Kimbulwana Project.

[h] Revised based on Upali et.al. (1997).

[i] The “desired level” of O&M in 1995 prices for major irrigation schemes.

[j] The “desired level” of O&M in 1995 prices for minor irrigation schemes (from World Bank 1992).

[k] All the parameters and assumptions are the same as in Aluwihare and Kikuchi (1991), except for price-related items which are converted to 1995 prices.

Sources: Aluwihare and Kikuchi (1991), except for VIRP (World Bank 1992), ISMP (Sheladia 1992), MIRP (World Bank 1995), and NIRP (World Bank 1999).

Annex table a-6.

Number of and investments by farmers on agro-wells and irrigation pumps in irrigation schemes in the dry zone of Sri Lanka, 1966-2000.[a]

	Number (1,000 units)				Investment (Rs million in 1995 prices)		
	Lined dug-well	Unlined dug-well	Tube-well	Pumps	Wells	Pumps	Total
1965	0.0	0.0	0.0	0.0	0.0	0.3	0.3
1966	0.0	0.0	0.0	0.0	0.0	0.1	0.1
1967	0.0	0.0	0.0	0.0	0.0	0.4	0.4
1968	0.0	0.0	0.0	0.1	0.0	0.6	0.6
1969	0.0	0.0	0.0	0.1	0.0	0.6	0.6
1970	0.0	0.0	0.0	0.2	0.0	2.3	2.3
1971	0.0	0.0	0.0	0.3	0.0	4.4	4.4
1972	0.0	0.0	0.0	0.7	0.0	10.1	10.1
1973	0.0	0.0	0.0	1.2	0.0	12.3	12.3
1974	0.0	0.0	0.0	1.7	0.0	14.6	14.6
1975	0.0	0.0	0.0	2.5	0.2	22.2	22.4
1976	0.0	0.0	0.0	3.3	0.2	19.4	19.6
1977	0.0	0.0	0.0	4.1	0.2	22.5	22.6
1978	0.0	0.0	0.0	4.9	0.2	21.8	21.9
1979	0.0	0.0	0.0	5.8	0.2	22.3	22.5
1980	0.0	0.0	0.0	6.7	0.2	25.8	26.0
1981	0.0	0.0	0.0	7.9	0.2	30.1	30.3
1982	0.0	0.0	0.0	9.2	0.2	35.1	35.3
1983	0.0	0.0	0.1	10.7	0.3	41.4	41.7
1984	0.1	0.0	0.1	12.7	4.1	53.3	57.4
1985	0.4	0.0	0.1	15.2	24.2	66.7	90.8
1986	0.7	0.0	0.2	18.0	16.2	72.1	88.3
1987	1.0	0.0	0.2	21.0	22.1	81.5	103.6
1988	1.5	0.0	0.3	24.5	35.0	93.4	128.4
1989	2.4	0.0	0.4	28.6	64.9	108.2	173.1
1990	4.8	0.1	0.5	34.5	158.5	159.2	317.7
1991	6.2	0.3	0.8	40.2	102.7	149.6	252.4
1992	7.9	0.5	1.2	46.2	113.0	161.0	274.1
1993	10.0	0.9	1.7	53.0	148.8	181.5	330.4
1994	11.8	1.5	2.4	60.2	129.1	192.0	321.1
1995	13.9	2.1	3.2	67.8	152.1	201.4	353.5
1996	16.4	3.0	4.2	76.0	176.2	219.4	395.6
1997	20.0	4.0	5.4	83.4	255.4	198.1	453.5
1998	24.0	5.2	6.7	90.7	283.8	193.9	477.7
1999	28.1	6.5	8.1	98.5	290.7	206.0	496.7
2000	32.5	8.2	9.8	106.9	311.3	224.2	535.4

[a] For details in the estimation see Kikuchi et al. (2001).

Appendix Table a-7.

Crops irrigated by well and pump, irrigation performance, and alternative crop.[a]

Type	Crop irrigated	Number of cropping	Yield t/ac	Value-added ratio[b] %	Income ratio[c] %	Output price Rs/kg	Irrigation		Data obtained in:
							Capacity[d] ac	Rate	
1 Well with pump	Big onion	x1 in yala	3.0	85	70	25	1	4 hours/day for 75 days; 4 block-rotation	System H and minor schemes in Kala Oya basin
2 Well with pump	Rice	x1 in yala	5.2	80	70	8	2	18 hours per irrigation x 24 irrigation per season	Minor schemes in Deduru Oya basin
3 Pump (river-lift)	Red onion	x1 in yala	3.0	70	60	40	1.25	24 hours per irrigation; x 9 per season	Kirindi Oya Scheme
4 Well with pump	Red onion	x3 in year[e]	4.0	50	40	40	2	6 hours/day for 65 days per season	Kalpitiya
5 Rainfed	Gingelly	x1 in yala	0.2	97	97	15	-[f]	-	Minor schemes in the dry zone

[a] Data are from our surveys.

[b] Gross value-added = total output value—current inputs.

[c] The ratio of farmers' income total output value.

[d] Irrigated area by a set of well+pump (for No. 3, by pump alone).

[e] Assume that one additional crop of red onion can be grown by a set of tube well and electric pump.

[f] Assume to be planted to 50% of area cultivated.

Annex B—Estimation of Rice Fertilizer Response Functions

As a basis for estimating the benefit of irrigation investments, we re-estimated rice fertilizer response functions for different variety groups using the data presented in Kikuchi and Aluwihare (1990). The re-estimation was attempted partly because the previous estimation of the functions at experimental fields was constrained by a limitation of the computer software then used and partly because changes in rice production during the last decade necessitate some adjustment of the functions at farm level.

Response functions at experimental fields: The estimation results of the response function of quadratic form using experiment data are presented in Appendix table b-1. In addition to season and growth duration dummies, intercept dummies are introduced to control differences among experiments. The results are essentially the same as the previous estimation for all variety types, except for the following points. First, the statistical fitting is far better than the previous estimation for all variety types. With significant improvements in the coefficient of determination, the quadratic nature of nitrogen response of rice yield is much clearer in the new estimation than the old one. Second, both the season and growth duration dummies are highly significant: rice yield in yala season is higher than in maha season and long-duration varieties yield better than short-duration varieties. At farm level, no significant yield difference has been observed between maha and yala seasons since the time of TVs. This may be explained by the tendency that farmers plant long-duration varieties in maha season and short-duration varieties in yala season. It is difficult to examine if this is the case, since available data on varieties do not give information beyond the TV-OIV-NIV distinction. In this study, we adopt a response function for each variety group not distinguishing the seasons.

Response functions at farm level: The fertilizer response functions at experimental field level are adjusted down to the farm level. Based on the estimate by Jayawardena et al. (1983) on the yield gap between research stations and farmers' fields, the response functions of TV and OIV in table b-1 are adjusted down vertically by 40%, including the average intercept, to arrive at the farm level functions under irrigated condition. In the case of NIV, the adjustment coefficient of 30% is adopted taking into account improvements in farmers' technology level in the last decade. The rice fertilizer response functions under irrigated condition thus estimated are as follows:

Traditional varieties (TV)

$$Y = 1600 + 10\ N - 0.09\ N^2$$

Old improved varieties (OIV)

$$Y = 1900 + 14\ N - 0.06\ N^2$$

New improved varieties (NIV)

$$Y = 2800 + 25\ N - 0.08\ N^2$$

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

Annex table b-1.

Estimated fertilizer response functions at experiment station fields.[a]

	Traditional varieties	Old improved varieties	New improved varieties
N	15.8	23.7	32.5
	(4.360)	(13.892)	(21.706)
N^2	-0.111	-0.095	-0.110
	(2.243)	(5.493)	(10.256)
Season[b]	1286	1819	1536
	(7.972)	(8.992)	(5.870)
Growth duration[c]	-	1384	1858
	-	(4.139)	(7.100)
Intercept (average of all experiments)	2714	3215	3990
Adj. R^2	0.796	0.922	0.932
Degree of Freedom	38	136	211
Number of dummy variables included[d]	16	60	69

[a] The fertilizer response function of the following quadratic form: $Y = a + bN - cN^2$, where Y=rice yield (kg/ha) and N=nitrogen input (kg/ha). Figures in parenthesis are t-ratio.

[b] Season dummy; maha=0 and yala=1.

[c] Growth duration dummy; short-duration (3-3.5 months)=0 and long-duration (4 months or longer)=1.

[d] Differences among experiments are controlled by intercept dummies.

Source: Original data from Kikuchi and Aluwihare (1990).

Literature Cited

Aluwihare, P.B.; and Kikuchi, M. 1991. *Irrigation investment trends in Sri Lanka: New construction and beyond*. Colombo:, Sri Lanka: International Irrigation Management Institute.

Amarasinghe, U. A.; R. Sakthivadivel, and H. Murray-Rust. 1998. *Impact Assessment of Rehabilitation Intervention in the Gal Oya Left Bank*. Research Paper 18. Colombo, Sri Lanka: International Irrigation Management Institute.

Ariyaratne, D. M. 1990. Future Strategy of the Irrigation Management Division. In *Resource mobilization for sustainable management: Proceedings of a workshop major irrigation schemes in Sri Lanka*. Colombo, Sri Lanka: International Irrigation Management Institute.

Barker R.; and M. Samad. 1998. *Food security and irrigation development in Sri Lanka: Past accomplishments and future prospects.* Paper presented at National Water Conference on Status and Future Directions of Water Research in Sri Lanka, BMICH, Colombo, Sri Lanka; November 4-6.

Hayami, Y.; and M. Kikuchi. 1999. *A rice village saga: The Three Decades of Green Revolution in the Philippines*. London: Macmillan.

International Irrigation Management Institute (IIMI). 1989. *Study on irrigation systems rehabilitation and improved operation and management, Vol. 3, Activity C: Financing the costs of irrigation.* A final report submitted to the Asian Development Bank. Colombo, Sri Lanka: IIMI.

Jayawardena, S. D. J.; K. Tanaka; and T. Watanabe. 1983. Potential productivity of rice in the low-country wet zone of Sri Lanka. *Japan Agricultural Research Quarterly.* 17 (2): 87-91.

Kikuchi, M.; and P. B. Aluwihare. 1990. Rice-fertilizer response functions: Estimation and applications. *Sri Lanka Journal of Agricultural Science*, 27, pp.114-137.

Kikuchi, M.; and Y. Hayami. 1978. Agricultural growth against a land resource constraint: A comparative history of Japan, Taiwan, Korea and the Philippines. *Journal of Economic History*, 38 (4), 839-864.

Kikuchi, M.; A. Maruyama; and Y. Hayami. 2000. "*Investment Inducements to Public Infrastructure: Irrigation in the Philippines and Sri Lanka since Independance,*" Los Bonos : International Rice Research (typescript).

Kikuchi, M.; A. Maruyama; and Y. Hayami. 2001. "*Phases of Irrigation Development in Asian Tropics: A Case Study of the Philippines and Sri Lanka,"* Matsudo: Department of Agricultural Economics, Chiba University (typescript).

Kikuchi, M.; P. Weligamage; R. Barker; M. Samad; H. Khono; and H.M. Somaratne. 2001. *Agro-well and Pump in Irrigation schemes in the Dry Zone of Sri Lanka: Past Trend, Present Status and Future Prospect*. Colombo, Sri Lanka: International Water Management Institute (typescript).

Kikuchi, M.; R. Barker; M. Samad; and P. Weligamage. 2002. Comparative Advantage of Rice Production in an Ex-rice Importing Country: The Case of Sri Lanka. In *Sustainable Agriculture, Poverty and Food Security,* Ed. S.S Acharya, Surjit Singh and Vidya Sagar. Jaipur, India: Rawat Publishers.

Panabokke, C. R. Undated. "*Aspects of Groundwater Management in Sri Lanka,"* Colombo, Sri Lanka: International Water Management Institute (typescript).

Ratnayake, R. 1997. *Modernization of irrigation schemes: past experiences and future options in Sri Lanka,* Bangkok: FAO, pp.229-236.

Samad, M.; and D. Vermillion. 1999. *Assessment of Participatory Irrigation Management in Sri Lanka: Partial Reforms, Partial Benefits*. Research Report 34. Colombo, Sri Lanka: International Water Management Institute.

Sakurai, T. ;1999. *Tank irrigation as local commons: The case of Tamil Nadu in India* (in Japanese). Quarterly Journal of Agricultural Economy 53 (2): 1-50.

Shah, T. 1993. *Groundwater Markets and Irrigation Development: Political Economy and Practical Policy.* Bombay: Oxford University Press.

Sheladia. 1990. *Annual maintenance plan: Giritale scheme-DCO Puranagama*. A draft report, Colombo, Sri Lanka: Sheladia Inc.

Sheladia. 1990. *Final project report: Executive summary, report and annexures*. Colombo, SriLanka: Sheladia Inc.

World Bank. 1992. *Project completion report: Sri Lanka, Village Irrigation Rehabilitation Project*. Washington, D.C. World Bank.

World Bank. 1993. *Project completion report: Sri Lanka, Third Mahaweli Ganga Development Project*. Washington, D.C. World Bank.

World Bank. 1995. *Project completion report: Sri Lanka, Major Irrigation Rehabilitation Project.* Washington, D.C. World Bank.

Research Reports

49. *Basin-Level Use and Productivity of Water: Examples from South Asia.* David Molden, R. Sakthivadivel, and Zaigham Habib, 2000.

50. *Modeling Scenarios for Water Allocation in the Gediz Basin, Turkey.* Geoff Kite, Peter Droogers, Hammond Murray-Rust, and Koos de Voogt, 2001.

51. *Valuing Water in Irrigated Agriculture and Reservoir Fisheries: A Multiple Use Irrigation System in Sri Lanka.* Mary E. Renwick, 2001.

52. *Charging for Irrigation Water: The Issues and Options, with a Case Study from Iran.* C. J. Perry, 2001.

53. *Estimating Productivity of Water at Different Spatial Scales Using Simulation Modeling.* Peter Droogers, and Geoff Kite, 2001.

54. *Wells and Welfare in the Ganga Basin: Public Policy and Private Initiative in Eastern Uttar Pradesh, India.* Tushaar Shah, 2001.

55. *Water Scarcity and Managing Seasonal Water Crisis: Lessons from the Kirindi Oya Project in Sri Lanka.* R. Sakthivadivel, Ronald Loeve, Upali A. Amarasinghe, and Manju Hemakumara, 2001.

56. *Hydronomic Zones for Developing Basin Water Conservation Strategies.* David J. Molden, Jack Keller, and R. Sakthivadivel, 2001.

57. *Small Irrigation Tanks as a Source of Malaria Mosquito Vectors: A Study in North-Central Sri Lanka.* Felix P. Amerasinghe, Flemming Konradsen, Wim van der Hoek, Priyanie H. Amerasinghe, J. P. W. Gunawardena, K. T. Fonseka and G. Jayasinghe, 2001.

58. *Fundamentals of Smallholder Irrigation: The Structured System Concept.* B. Albinson and C. J. Perry. 2001.

59. *A Gender Performance Indicator for Irrigation: Concepts, Tools and Applications.* B. van Koppen. 2001.

60. *Institutional Alternatives in African Smallholder Irrigation: Lessons from International Experience with Irrigation Management Transfer.* Tushaar Shah, Barbara van Koppen, Douglas Merrey, Marna de Lange and Madar Samad. 2002.

61. *Poverty Dimensions of Irrigation Management Transfer in Large-Scale Canal Irrigation in Andra Pradesh and Gujarat, India.* Barbara van Koppen, R. Parthasarathy and Constantina Safiliou. 2002.

62. *Irrigation Sector in Sri Lanka: Recent Investment Trends and the Development Path Ahead.* M. Kikuchi, R. Barker, P. Weligamage and M. Samad. 2002

Postal Address:
P O Box 2075
Colombo
Sri Lanka

Location:
127, Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Tel:
+94-1-787404

Fax:
+94-1-786854

E-mail:
iwmi@cgiar.org

Website:
http://www.iwmi.org

International
Water Management
Institute

FUTURE HARVEST
IWMI is a Future Harvest Center
supported by the CGIAR

ISSN 1026-0862
ISBN 92-9090-501-8