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IRRIGATION INVESTMENT AND MANAGEMENT IN ASIA:

TRENDS, PRIORITIES, AND POLICY DIRECTIONS

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ABSTRACT

The paper addresses the implications of declining productivity growth for rice and wheat in Asia, and the parallel changes in irrigation investment patterns, for future irrigation investment and management policies. The general economic case for increased public investment in new irrigation is examined, the potential and cost-effectiveness for improvement of existing irrigation systems are assessed, issues and policies related to the expansion of private investment are discussed, and policy implications for irrigation investment and management strategy in Asia are presented.

The paper concludes that the substantial cutback in public investment during the 1980s was a largely appropriate response to declining world rice and wheat prices and the rapidly increasing capital costs of irrigation. However, a modestly higher shadow price for rice and wheat should be utilized in evaluation of irrigation and other investments, due to the endogeneity of world prices relative to irrigation investments and due to asymmetric risk concerns. With higher shadow prices, the portfolio of cost-effective irrigation projects would increase somewhat compared to projected levels, moderately boosting expenditures on irrigation.

Selective investment in irrigation rehabilitation, management reforms, and other interventions to improve the efficiency and performance of irrigation systems should continue to have an important role in future development in Asian irrigation. However, the rates of return, and aggregate production and income benefits of these investments do not appear to be as high as many observes have estimated. Careful identification of systems to be rehabilitated and selection of high-payoff points of intervention within the systems would improve the cost-effectiveness of these interventions.

Expansion of private investment in irrigation, particularly tubewells, is very promising. While the government role in encouraging private investment should be indirect--consisting primarily of sustenance of an appropriate legal/institutional environment and provision of adequate public goods and services--it is nevertheless critical to expansion of private investment. Targeted investments in public goods, such as energy and roads, which can facilitate the expansion of conjunctive use of tubewells and canal irrigation, should be particularly productive due to the largely unexploited positive externalities arising from conjunctive use.

EXECUTIVE SUMMARY

The main objective of the paper is to address the implications for future irrigation investment and management policies of changes over the past ten years in productivity growth for rice and wheat, which are the dominant crops in irrigated areas, and the parallel changes in irrigation investment patterns. The paper is organized as follows: First, trends in rice and wheat area, yield, and production and trends in irrigation development and investment for Asia and five case study countries: India, Indonesia, Philippines, Sri Lanka, and Thailand, are discussed. Second, the general economic case for increased public investment in new irrigation is examined. Third, the potential for and cost-effectiveness of improving existing irrigation systems are assessed. Fourth, issues and policies related to the expansion of private investment are discussed. The final section presents conclusions for irrigation investment and management strategy in Asia.

Although rice and wheat yields per hectare have increased in some countries in Asia (notably rice in Bangladesh and India), overall there has been a sharp decline in yields during the past decade. A number of factors have contributed to the slowdown in productivity growth for rice and wheat in Asia since the early 1980s, including declining world commodity prices; factors related to the process of intensification of rice and wheat production; and broad policy reforms and structural changes in economies, which have altered relative factor prices and incentive structures.

Sharp declines in world rice and wheat prices and increasing capital costs have resulted in reduced rates of investment for irrigation infrastructure; have led to a shift of land out of rice and wheat and into other crops; and have reduced the rates of increase in input use. At the same time, increased intensity of farming, particularly in irrigated areas, has led to diminishing marginal returns to increased input use, and caused degradation of land in some areas. Changes in government policies, such as reduction of fertilizer and other subsidies to agriculture, have also contributed to reduced growth.

Reductions in the rate of expansion of irrigation investment have been particularly dramatic. Aggregate lending and assistance for irrigation in Asia by the international donors declined by half from the late 1970s to the late 1980s. Case studies of several countries in Asia indicate that total irrigation investment expenditures show similar declines in rate of investment in irrigation during this period.

There are sharp differences of opinion as to the relative importance of the various factors which have contributed to the slowdown in productivity growth in many areas of Asia, and following from these different interpretations are quite different implications for future irrigation investment and management policies. Two general scenarios are discussed in the paper.

Scenario 1: Relatively rapid crop productivity growth. The optimistic growth scenario perspective is based on a judgement that recent slowdowns in production growth are

appropriate responses to changes in relative prices and government reforms, and that growth in food grain production can be sustained through normal technological improvements. Hybrid rice and new plant types will permit significant yield breakthroughs in the near future. This technological growth potential, combined with increases in income and continued rapid urbanization which induce diversification of diets from basic food grains to higher valued commodities, will cause world prices for rice and wheat to remain low. With continuing low prices and increasingly high per hectare capital costs for new irrigation development, reductions in the rate of irrigation investment have been appropriate, as investment in new irrigation remains unattractive relative to alternative investments in agricultural research and technology.

Instead of investing in new public irrigation systems, proponents of this scenario argue that it would be more appropriate to invest in improving the efficiency of existing irrigation systems and to encourage private investment in small-scale irrigation. With the rapid escalation of capital costs of new irrigation, the logical alternative to further expansion is intensification and increased efficiency in existing irrigation systems. As a corollary, continued subsidies to high cost large scale public irrigation would tend to drive out private investment in irrigation, which must bear the full economic costs of the investment. It would be more effective to encourage private investment through efficient provision of supporting public goods.

Scenario 2: Relatively slow crop productivity growth. The alternative scenario holds that the sharp irrigation investment decline together with other technology constraints raise serious questions whether desired levels of food grain productivity growth can be maintained. The impact of declining investments in the 1980s will be felt most strongly during the 1990s, further exacerbating the slowdown in new area irrigated and crop yield growth. Recent declines in productivity growth in those countries which have the highest rates of adoption of modern technology indicate that it will be increasingly difficult to accelerate yields through technology-based growth. According to this scenario, it is therefore essential to expand investments in new irrigated area in addition to improving existing systems, in order to maintain desired growth rates in grain production.

How can increased irrigation investments be justified, given the low rates of return due to high capital costs and low world rice and wheat prices? This scenario argues that modification of methods for evaluating irrigation investments to better incorporate long-term costs and benefits would justify a higher level of irrigation investment than currently contemplated.

According to this argument, in order to improve the allocation of irrigation investment, traditional cost-benefit analysis should be extended to incorporate endogenous world prices through feedback from the effect of total irrigation investment on prices, to better incorporate risk considerations, incorporate the adjustment costs of irrigation agencies, and take account of secondary benefits of irrigation. These modifications would assist in smoothing the cycles in investment and production, reducing the potentially high costs of this excessive variability.

The paper then proceeds to evaluate these alternative scenarios, and, based on this evaluation, draws broad conclusions for future irrigation and management strategies in Asia. The paper notes that deriving general conclusions on irrigation investment and management strategies is difficult. Even broad strategies tend to be country-specific, and implementable decisions quickly become region- and project-specific. Nevertheless, the following conclusions are drawn from the analysis.

First, the substantial cutback in public investment during the 1980s appears to be an appropriate response to declining world rice and wheat prices and the rapidly increasing capital costs of irrigation. Rapid expansion of inefficient, high cost public irrigation to expand production and keep prices low will be self-defeating. If capital costs are passed on to farmers (which governments have historically been unable to do) the costs will be capitalized into food prices; if costs are subsidized by the government from general revenues, consumers will pay out of one pocket what they are saving in the other pocket from lower food prices.

Nevertheless, there appears to be merit in arguments that, due to the endogeneity of world prices and asymmetric risk concerns, a modestly higher shadow price for rice and wheat could be utilized in evaluation of irrigation (and other) investments. These modified shadow prices would reflect the probable long term effects of reduction in irrigation investment over the past few years. If shadow prices were revised slightly upward, the portfolio of cost-effective new irrigation projects would increase somewhat compared to current levels, moderately boosting expenditures on new irrigation. Development of policy models to analyze the investment-production-price relationships for major commodities should have high payoffs in terms of improving investment decision-making.

Selective investment in irrigation rehabilitation, management reforms, and other interventions to improve the efficiency and performance of irrigation systems should continue to have an important role in future development in Asian irrigation. However, the rates of return, aggregate production and income payoffs, and absorptive capacity of these investments do not appear to be as high as many observers have estimated. The tendency toward high cost rehabilitations to reconstruct and modernize systems from the dam to the farmers' fields should be avoided. Careful identification of systems to be rehabilitated and selection of high-payoff points of intervention within the systems will improve the cost-effectiveness of these interventions.

Expansion of private investment in irrigation, particularly tubewells, is very promising. While the government role in encouraging private investment should be indirect--consisting primarily of sustenance of an appropriate legal/institutional environment and provision of adequate public goods and services--it is nevertheless critical to the expansion of private investment. Targeted investments in public goods, such as energy and roads, which can facilitate the expansion of conjunctive use of tubewells and canal irrigation, should be particularly productive due to the largely unexploited positive externalities arising from conjunctive use.

1. INTRODUCTION

The introduction and rapid spread of high yielding rice and wheat varieties combined with heavy investment in irrigation and rapid growth in fertilizer use in the late 1960s and the 1970s resulted in strong output growth for these crops in Asia (Dalrymple, 1986; Herdt and Capule, 1983; Byerlee, 1990). For rice, the yield growth rate in Asia increased from 1.7 percent per annum during 1958-66 (before the spread of modern technology) to 2.3 percent per annum during 1966-74 and 2.9 percent during 1974-82 (Table 1). However, growth in rice yield has slowed to 1.9 percent annually since the early 1980s.

Yield growth was the primary contributor to rice output growth throughout these periods. Area expansion contributed about one-third of Asian rice output growth, 1966-74, but virtually halted after that. The rate of growth in output in Asia therefore also declined in the 1980s, from an annual growth rate of 3.1 percent, 1974-82, to 2.2 percent during the period beginning in 1982. The pattern of growth, however, varied significantly by subregion. China and Southeast Asia experienced substantial declines in the rate of yield growth during the latter period. By contrast, rice yield growth increased dramatically in India during the 1980s, and was slightly higher in the rest of South Asia (due to strong growth in Bangladesh).

Annual rates of growth for area, yield, and production of wheat have also declined since the early 1980s. Area growth accounted for over one-third of production growth for wheat in Asia, 1966-74, and about one-fourth of production growth in 1974-82 (Table 2). After 1982, area growth for Asia was virtually nil. Yield growth for wheat in Asia was 4.1 percent from 1966-74 and 4.4 percent for 1974-82, before declining to 2.7 percent annually after 1982. The rate of growth in total wheat production in the latter period was about half the rate of growth in the previous period. Comparable declines in production growth were experienced in the main wheat growing areas of China, India, and the rest of South Asia.

A number of factors have contributed to the slowdown in productivity growth for rice and wheat in Asia since the early 1980s, including declining world commodity prices (Figure 1); factors related to the process of intensification of rice and wheat production; and broad policy reforms and structural changes in economies, which have altered relative factor prices and incentive structures. Sharp declines in the world rice and wheat prices and increasing capital costs have resulted in reduced rates of investments for irrigation infrastructure; have led to a shift of land out of rice and wheat and into other crops; and have reduced the rates of increase in input use. At the same time, increased intensity of farming, particularly in irrigated areas, has led to diminishing marginal returns to increased input use, and has caused degradation of land in some areas (Rosegrant and Pingali, 1991). Changes in government policies, such as reduction of fertilizer and other subsidies to agriculture, have also contributed to reduced growth. Broader policy and structural changes, such as institutional reforms in China, have shifted effective relative factor prices.

Reductions in the rate of expansion of irrigation investment have been particularly dramatic. Aggregate lending and assistance for irrigation in Asia and the Middle East/North Africa in the 1970s and 1980s by the four main financial donors for irrigation development--the

World Bank, Asian Development Bank (ADB), the U.S. Agency for International Development (USAID), and the Japanese Overseas Economic Cooperation Fund (OECF)--reached its peak in real terms in 1977-79, and by 1986/87 it was less than 50 percent of the 1977-79 level. Total domestic and foreign irrigation investment expenditures for individual countries in Asia showed similar declines in rate of investment in irrigation during this period.

What are the implications of these changes in productivity growth for rice and wheat (which are the dominant crops in irrigated areas) and the parallel changes in irrigation investment patterns for future irrigation investment and management policies? There are sharp differences of opinion as to the relative importance of the various factors which have contributed to the slowdown in productivity growth in many areas of Asia, and following from these different interpretations are quite different implications for future irrigation investment and management policies. Two general scenarios for future productivity growth can be constructed.

Scenario 1: Relatively rapid crop productivity growth. The optimistic growth scenario perspective is based on a judgement that recent slowdowns in production growth are appropriate responses to changes in relative prices and government reforms, and that growth in food grain production can be sustained through normal technological improvements. According to this scenario, the increased rates of productivity growth in India and Bangladesh, and in regions within countries which have had aggregate growth slowdowns, indicate the continued existence of exploitable yield gaps with existing and pipeline technology and projected relative prices. In addition, the recent factor and product price changes will continue to induce fine-tuning of technology even in intensively cropped areas, which will provide further productivity growth. Hybrid rice and new plant types will permit significant yield breakthroughs in the near future.

This technological growth potential, combined with increases in income and continued rapid urbanization, which induce diversification of diets from basic food grains to higher valued commodities, will cause world prices for rice and wheat to remain low. With continuing low prices and increasingly high per hectare capital costs for new irrigation development, reductions in the rate of irrigation investment have been appropriate, and investment in new irrigation remains unattractive relative to alternative investments in agricultural research, extension, and technology.

Proponents of this scenario argue that, instead of investing in new public irrigation systems, it is more appropriate to invest in improving the efficiency of existing irrigation systems, and to encourage private investment in small-scale irrigation. The present situation with respect to irrigation is analogous to the more general pattern of productivity growth in rice and wheat: where as the extensive land margin is used up, costs of further area expansion become prohibitive, and intensification of existing production areas becomes more profitable. Similarly, with the rapid escalation of capital costs of new irrigation, the logical alternative to further expansion is intensification and increased efficiency in existing irrigation systems. As a corollary, continued subsidies to high cost large-scale public irrigation would tend to drive out private investment in irrigation, which must bear higher if not the full, economic costs of the

investment. It would be more effective to encourage private investment through efficient provision of supporting public goods.

Scenario 2: Relatively slow crop productivity growth. An alternative scenario holds that the sharp drop in irrigation investment, together with other technology constraints, raises serious questions as to whether desired levels of food grain productivity growth can be maintained in the future. The impact of declining investments in the 1980s will be felt most strongly during the 1990s, further exacerbating the slowdown in new area irrigated and crop yield growth. Recent declines in productivity growth in those countries which have the highest rates of adoption of modern technology indicate that it will be increasingly difficulty to accelerate yields through technology-based growth. According to this scenario, it is therefore essential to expand investments in new irrigated area in addition to improving existing systems, in order to maintain appropriate growth rates in grain production.

How can increased irrigation investments be justified given the low rates of return due to high capital costs and low world rice and wheat prices? Proponents of this scenario argue that modification of methods for evaluating irrigation investments to better incorporate long-term costs and benefits would justify a higher level of irrigation investment than currently contemplated. As relatively long-term investments, with 30-to-50 year operating lives and substantial salvage value, irrigation investment decisions should be strongly influenced by long-term trends in required foodgrain production and potential benefit, with short-term circumstances being significantly less influential. Instead, although careful cost-benefit analysis tries to place the estimation of costs and benefits in the appropriate time frame, the difficulties of predicting the future and the pressure of present circumstances tend to introduce a bias toward consideration of short-term economic conditions, particularly world rice price and irrigation investment costs (Levine, et al. 1988).

The most costly consequence of investment decisions based on shorter time perspective is excessive variability in investment patterns that can in turn induce high variability in growth rates in agricultural production, particularly rice. The cyclical pattern of investment and production further exacerbates domestic price variability, creating uncertainty for farmer production decisions, and increasing the costs and difficulties of other policies designed to maintain stable growth.

According to this argument, in order to improve the allocation of irrigation investment, traditional cost-benefit analysis should be extended to incorporate endogenous world prices through feedback from the effect of total irrigation investment to prices, to better incorporate risk considerations, to incorporate the adjustment costs of irrigation agencies, and to take account of the secondary benefits of irrigation. These modifications would assist in smoothing the cycles in investment and production, reducing the potentially high costs of this excessive variability.

To fully explore these alternative scenarios and their implications for irrigation investment and management policy, it would be necessary to do an integrated analysis of supply

and demand, sources of growth, and investment rates of return for individual countries, and to link these country level analyses through a world trade model to explore long term production and price scenarios. Specific irrigation investment strategies developed from this type of analysis would necessarily be highly country-specific. However, it is possible to derive general recommendations for broad irrigation investment and management strategies through an examination of trends in irrigation investment and performance.

The remainder of the paper is organized as follows. First, trends in irrigation development and investment in Asia and five case study countries: India, Indonesia, Philippines, Sri Lanka, and Thailand; will be examined. Second, the general economic case for increased public investment in new irrigation will be examined. Third, the potential and cost-effectiveness of improving existing irrigation systems will be examined. Fourth, issues and policies related to the expansion of private investment will be discussed. Finally, conclusions for irrigation investment and management strategy in Asia will be discussed.

2. TRENDS IN IRRIGATED AREA AND IRRIGATION INVESTMENT

This section is divided into three parts, the first dealing with aggregate trends in new area irrigated, the second dealing with trends in irrigation investment by four major international lenders, and the third assessing trends in irrigation expenditures for five case study countries, India, Indonesia, Philippines, Sri Lanka, and Thailand. A more detailed discussion of trends in area irrigated and irrigation investment for the five case study countries is presented in the Appendix.

2.1 Trends in Aggregate Irrigated Area, Asia

In 1988, the world's net irrigated area was 229 M hectares. Of this amount, 143 M hectares were in Asia, 62 percent of the worldwide total (Table 3 and Figure 2). Over one-third of arable land in Asia is irrigated. The total area irrigated in Asia grew from a base of around 100 M hectares in 1966, an overall increase of 43 percent. The share of the world's irrigation contributed by Asia declined over that period by nearly three percentage points, from 65.3 percent to 62.5 (Table 2).

The pattern of growth of irrigated area in Asia is shown in Table 4. Annual average growth rates over the full period, 1960-88 range from Southeast Asia's 2.7 percent to East Asia's 1.1 percent, with South Asia growing at a rate of 1.7 percent. In terms of shares, however, the region of strongest growth, Southeast Asia, contributes only 13 percent of the region's net irrigated area, while South Asia provides about 15 percent, India 33 percent and China 35 percent (Figure 3).

As shown in Table 4, in Asia as a whole and in each sub-region, there has been a sharp decline in the rate of growth in irrigated area. In South Asia, the growth rate in irrigated area dropped from 2.8 percent, 1975-80, to 1.8 percent in 1980-85, and to 0.1 percent, 1985-88. In East Asia, growth in irrigated area was over 2 percent annually through the mid-1970s, but was virtually stagnant in the 1980s. In Southeast Asia the growth rate remained strong through the mid-1980s, but declined sharply from 4.1 percent, 1980-85, to 1.5 percent, 1985-88.

2.2 Trends in Lending for Irrigation by International Agencies

The overall decline in the rate of growth in aggregate irrigated area in Asia has been accompanied by a sharp decline in lending for irrigation by international donors. This section assesses trends in irrigation investment in South and Southeast Asia by four major donors, the World Bank, Asian Development Bank (ADB), the United States Agency for International Development (USAID), and the Japanese Overseas Economic Cooperation Fund (OECF).

The investment data utilized are the total amount of loans and assistance in the year those loans and assistance are approved. Time series data on actual disbursements of the loans and assistance are not available. The data is presented in real terms, with current loans and

assistance deflated by the Industry Price Deflator published in the World Tables 1987. For those countries where the Industry Price Deflator was not available, an alternative price index was utilized, chosen from the following, in order of the preference when available: implicit GAP deflator, agricultural price index, wholesale price index, and consumer price index.

As shown in Table 5, the World Bank has been the largest lending institution for irrigation in these regions. Of the total lending by the World Bank, ADB and OECF, the World Bank provided 87 percent in 1974-76 and 75-80 percent in subsequent periods. With USAID included in the summation, the World Bank accounted for about 70 percent of the total lending and assistance in the last three periods. ADB is the second largest lender for irrigation, accounting for about 17 percent of total loans since 1977. ADB is particularly significant in Southeast Asia, where it has accounted for about one-third of total irrigation loans and assistance. USAID and OECF together account for a little over 10 percent of total for irrigation.

Tables 5 shows that there has been a large decline in real lending and assistance for irrigation from the four donors since the peak periods of 1977-79. Lending has declined in each period since 1977-79, and by 1986-87 total lending was just over 50 percent of the 1977-79 level. The decline was the sharpest after the 1980-82 period, with a drop in lending and assistance from the four donors of 40 percent through 1986-87.

Average lending and assistance for irrigation in South Asia was highest in 1980-82, at $820 million, before declining by more than one-half to $397 million in 1986-87 (Table 6). The largest proportional decline from peak investment levels, however, has been in Southeast Asia. Lending for irrigation from World Bank, ADB, and OECF declined from an annual average of $653 million in 1977-79 to $202 million in 1986-87, a decline of two-thirds (Table 7). World Bank average lending for irrigation in Southeast Asia in 1986-87 was only one-fifth of the level in 1977-79.

2.3 Trends in Public Expenditures for New Irrigation Construction

Total public expenditures for irrigation for individual countries also declined significantly during the 1980s (Table 8). In the Philippines, annual expenditures on irrigation investment in the late 1980s were only one-third the level of the early 1980s. Annual expenditures in Sri Lanka were cut nearly in half between the late 1970s and the late 1980s. Declines in the late 1980s from peak expenditure levels in India, Indonesia, and Thailand range from 10 percent to 30 percent.

In summary, both international lenders and the five countries assessed above have reduced their levels of expenditure on irrigation investment over the past decade. The degree of decline in investment has varied, with particularly large declines in the Philippines and Sri Lanka, and somewhat less dramatic reductions in India, Indonesia, and Thailand, but the reductions in recent years are significant in each country. In Asia as a whole and for each

region in Asia, there has also been a substantial decline in the rate of growth in new irrigated area, beginning in the early to mid-1980s.

What has caused this decline in the rate of irrigation investment? A number of contributing factors can be identified: (a) the relatively favorable food security situation in the region as a whole and the corresponding low level of rice and other foodgrain prices; (b) the large public and foreign debt loads carried by most of the agriculturally-based economies in the region; (c) the declining share of unexploited irrigation development potential in many countries in the region, and the correspondingly increasing per hectare cost of development; and (d) stiffening political resistance from the environmental interests and those displaced or otherwise negatively affected by irrigation development.

A recent series of econometric studies, which attempt to explain public irrigation investment in Indonesia, Philippines, Sri Lanka, and Thailand, all show that among the most important causes of declining investment are the decline in world rice prices and the increasing real costs per hectare of new irrigation development (Aluwihare and Kikuchi, 1990; Rosegrant and Pasandaran, 1990; Rosegrant and Mongkolsmai, 1990; Svendsen and Ramirez, 1990).

The decline in real commodity prices was shown in Figure 1. Table 9 summarizes trends in real capital costs for new irrigation systems in the five case study countries. All countries show large increases in the costs per hectare of investment over the past two decades. In India and Indonesia, the real costs of new irrigation have more than doubled since the late 1960s and early 1970s; in the Philippines, costs have increased by more than 50 percent; in Sri Lanka, they have tripled; and in Thailand they have increased by 40 percent. The result of these increases in costs and declining prices are low rates of return for new irrigation construction. Aluwihare and Kikuchi (1990), for example, show benefit cost ratios for new construction in Sri Lanka declining from 2.1 in 1970-74 to 0.7 in 1985-89.

3. STRATEGIES FOR INVESTMENT IN NEW IRRIGATION

The trends for irrigation investment in Asia clearly show reduced rates of real investment and declining growth in irrigated area induced by the drop in world commodity prices and rising costs of irrigation. The policy question is: has the slowdown in investment been an appropriate response to the declining social profitability of irrigation, or are there factors in the evaluation process for irrigation investments which have lead to an overreaction to declining prices and increasing costs, and consequently to underinvestment in irrigation? At least four arguments can be advanced to suggest that current investment procedures will lead to underinvestment.

1. World prices are endogenous to total irrigation investment. In most project evaluations undertaken by international donors and national governments, the world commodity price projections of the World Bank are utilized as shadow prices. For any given irrigation project it can be assumed, for purposes of cost-benefit analysis, that these projected world prices are exogenous, since the incremental output from an individual project will not affect world prices. However, world prices are partly a function of total irrigation (and other) investment. As described above, irrigation investment decisions by international lenders and by many countries are responsive to world prices. A large downward shift in irrigation investment due to declining prices will tend to reduce production, and to put upward pressure on prices. These feedback effects from irrigation investment to prices should be considered in setting the shadow price for commodities in project analysis, but do not appear to be fully accounted for in the commodity price projections.

Would explicit recognition and analysis of the world prices of rice and wheat as a function of irrigation and other investments make an important difference in the shadow prices? To properly analyze this issue would require utilization of detailed supply and demand models for rice, wheat, and related commodities for major producing and consuming countries and regions linked within a world commodity trade model. Such an effort is likely to have a strong policy pay-off.

This type of model is not currently available, but indicative analyses provide some evidence on the possible magnitude of effects of declines in Asian rice production on world rice prices. Timmer (1986) estimated, based on prices in the early 1980s, that each additional million metric tons of Indonesian rice imports would boost world prices about $50/mt from the level of $200/mt. Mitchell (1991) has estimated that an additional million metric tons of Philippine rice imports would increase the world price by $21.8/mt. These estimates should be considered short term effects, which do not fully account for subsequent longer term increases in world rice supply which would be induced by the increase in prices. The long term world price effect of increased imports would therefore be lower than these estimates.

An indicative estimate of longer term price effects can be done using a dynamic version of the SWOPSIM world commodity trade model which has been developed by Oga, based on the static version of model (Roningen, Sullivan, and Dixit 1991). A base run of the model is

first made using FAO projected production trends for rice in Asian countries estimated prior to the large cutbacks in irrigation. A second simulation is then run assuming a 50 percent decline in production trends for rice in Asian countries. The second simulation is intended to represent a worst case impact on production of declining irrigation investment. The simulated decline in production of rice in the second scenario results in a 10 percent increase in the world price of rice in the year 2000 compared to the first scenario.

It must be stressed that this indicative analysis does not allow a direct link from irrigation investment reduction to productivity declines; this link would require considerable additional modeling. The results do indicate that declining investment in irrigation which reduces production growth broadly in Asia would also cause increases in world prices, but that these increases are likely to be small. It may be appropriate to adjust the shadow price of rice modestly upward relative to projected world prices.

2. Risk and uncertainty with asymmetric outcomes. Cost-benefit analysis generally is done utilizing expected prices, costs, and benefits, without formal consideration of the probability distributions of outcomes. To the extent that distributions of prices or returns are skewed so that there is a higher probability of "bad" outcomes than "good" outcomes, it may be appropriate to take more explicit account of risk and uncertainty. Mitchell (1991) has undertaken an initial exploration of this issue with respect to Philippine rice import costs. He shows that the variability of rice prices is skewed so that high prices are more likely than low prices. The probability distribution of world prices, combined with the pattern of variability of domestic production, increases the long term average import cost, because there is a higher probability of imports during periods of relatively high world prices. This risk effect is such that a shift on average 1 million metric tons of Philippine rice imports would increase the marginal import cost by $17/mt (in addition to the import-price effect described above). These effects should also be analyzed in more detail using structural supply/demand trade models, but again indicate the possibility of using slightly higher shadow prices for rice.

3. Adjustment costs for irrigation agencies. Among the consequences of decisions based on shorter time perspectives are difficulties in making institutional and organizational adjustments. These difficulties include fluctuating budget allocations, relatively large variations in demand for irrigation development skills with shortages at construction time, significant problems relating to quality of construction, and crash programs of training followed by relatively long periods of employment stagnation. Illustrative of this latter situation are the cases of Bihar and Uttar Pradesh in India where there was a spurt of hiring during a major construction effort, followed by lay-offs and no hiring of engineers by the irrigation departments in the past five years. The boom/bust cycle prevents development of appropriate institutional responses to changing needs.

This process can be understood using an adjustment-cost approach first suggested by Eisner and Strotz (1963) and elaborated by Clark (1979). In this model the irrigation agency pays a penalty for having a capital stock (K) different from the optimal level determined using cost-benefit analysis, and incurs adjustment costs, A, in trying to shift to the optimal level:

$$A = f(K^d - K) + g(K - K_{-1}), f(0) = g(0) = 0;$$

$$\text{otherwise}, f > 0, g > 0,$$

where,

$f(\bullet)$ = cost of having a capital stock different from K^d, the static optimum for the output of the current period

$g(\bullet)$ = cost of adjusting the capital stock.

The optimal net investment undertaken is the one that minimizes costs in the trade-off between f (having too much or too little capital) and g (incurring costs of adjustment). If g displays the property that adjustment costs increase more than in proportion to changes in investment, then partial adjustment is optimal, and investment should move the capital stock only part way toward its desired level in any one period. This argument can justify a degree of counter-cyclical smoothing of the adjustment in investment levels to changes in prices. However, it should not be used to justify entrenched irrigation bureaucracies. To the extent that the changes in prices represent a new equilibrium level, it would be better to incur the adjustment costs and release resources for other activities.

4. Secondary benefits of irrigation. Cost-benefit analysis generally measures only the direct benefits of investment projects. Large investment projects also normally cause an increase in economic activity in the rest of the economy, and this increase may, in turn, induce increased productivity in the original project. Thus the total effects of the project on incomes and the net demands for goods and services in the economy will be different from its direct effects. These are usually termed indirect, secondary, or "downstream" effects. For example, Bell, Hazell and Slade (1982) found, in an analysis of the Muda irrigation project in Malaysia, that the indirect effects were large: about 80 cents of additional value added was generated in the region for each dollar of value added generated directly.

However, secondary benefits are not limited to irrigation investment. Ahmed and Hossain (1990) have shown the importance of secondary benefits of rural roads and infrastructure in Bangladesh, which include an important influence on the diffusion of technology and the efficiency of resource use, improved distribution of fertilizers, an increased rate of adoption of small-scale irrigation devices, and improved labor mobility, credit availability, and market information. There appears to be no evidence of a higher propensity for generation of secondary benefits from irrigation investment compared to other types of large-scale investment. The existence of secondary benefits therefore cannot justify higher levels of irrigation investment.

4. IRRIGATION SYSTEM IMPROVEMENT

With the rapid escalation of the cost of developing new irrigated land, as shown above, a logical alternative to further expansion is investment in improving the performance of existing irrigation schemes. Indeed there has been high optimism in many quarters that this improvement process would provide very large production benefits and a concomitant increase in rural incomes. Chambers (1988) estimates that improved water supplies could raise "significantly irrigated" area from canals in India by half (from 16 to 24 million hectares) which would then lead to "a doubling or more of yields.... Production from canal irrigation would triple...and the enduring impact could benefit millions of poor people...with livelihoods generated through the resulting prosperity." Bottrall (1981) suggests that measures to improve water distribution efficiency would be capable of generating average production increases of at least 20 percent, i.e. an incremental 30 million tons of paddy in South and Southeast Asia. He envisages a "water revolution" akin to the Green Revolution in its capacity to bring about substantial increases in crop production. However, both the physical processes of surface irrigation and the empirical evidence related to rehabilitation and management reform for improved water use efficiency suggest more modest and highly variable results.

4.1 Sources of Gain

To understand the range of options available for improving existing irrigation, it is useful to look at the mechanisms through which improvement efforts affect agricultural output. There are three principal mechanisms.

The first mechanism relates to the timeliness of irrigation deliveries to farmers -- making the deliveries more predictable and more coincident with the timing of the water requirements of crops being grown. Such improvements have both direct and indirect effects on output. The direct effect acts by reducing or eliminating periods of water stress on crops which tend to depress yields below those of an unstressed crop. In addition, the greater reliability of supply and the increased production potential of the crop under unstressed conditions can induce use of higher levels of complementary inputs such as fertilizer and labor, increasing both volume of output and net returns to cultivators. In the presence of appropriate environmental and market conditions, greater reliability can also induce a shift to alternative higher-value crops, thereby increasing the value of agricultural output from the system.

The second impact mechanism is the saving of water which is not used productively, and its application to unirrigated or underirrigated cropland. This mechanism acts on total production levels by increasing irrigated area rather than by raising yields per hectare. It can involve programs of physical works such as canal lining to reduce water conveyance losses and make more water available for application within the command. Along with the water saving itself, however, must go effective steps to apply the water where it will have the greatest impact in boosting yields. Otherwise, the impact on production may be relatively small. This effect can also be exploited by redistributing a fixed total volume of water within a command away

from more generously supplied areas to areas where its marginal value will be higher. This has often been a target of improvement programs which emphasize rotational irrigation and other forms of rationing. It is a difficult program to implement in practice, especially when imposed by a traditional hierarchical-structured administrative unit, as it implies redistributing a fixed resource among individual users.

Such programs are usually easier to implement when the quantity of the available resource is expanded at the same time, and many improvement programs combine an expansion in water supply with efforts to improve distribution and allocation. This tends to make impact assessment somewhat ambiguous, since it may not be clear which of the changes produced the measured impact on output, and at times effects attributed to the change in allocational procedures are simply due to the larger water supply.

As water resources become more fully allocated, opportunities for supply augmentation diminish, and in some areas such investments serve simply to shift water from one irrigation system or use to another. For example, this type of overinvestment appears to be occurring now along the Cauvery river in Southern India, as the upstream riparian state of Karnataka expands its irrigation capacity at the expense of the much older deltaic developments in neighboring Tamil Nadu. Up to some limit, such competition for supplies may induce greater efficiency in water use in downstream systems. At some point, however, possibilities for such efficiency gains become exhausted and new investment simply shifts production from one group of beneficiaries to another.

The third output-improving mechanism works through the reduction of waterlogging and salinity problems. Waterlogging and resultant problems of soil salinization lead directly in reduction of crop yields and to productive land going out of cultivation. These problems are exacerbated by overapplication of surface water to crops, and therefore steps taken to reduce overapplication of water can result directly in production increases due to reduced salinity levels and improved aeration in crop root zones.

All of these mechanisms can operate in response to improvements in system physical facilities, system water supply, rules of operation, managerial performance in implementing rules, or a combination of these factors. Improvement programs are usually more effective when interventions take place in more than one area. However, it is not always necessary to make thoroughgoing changes in all factors, as many rehabilitation efforts attempt. There remains much to learn about developing selected improvement packages which maximize net benefits of the intervention.

In addition to the impacts that improved irrigation performance has on crop outputs, other effects are sometimes sought, even though they may not be related to increased system agricultural output. These include increased equity of benefit distribution among project area residents; increased local or regional food self-reliance, especially where markets are poorly developed; or increased agricultural employment. Typically, however, these aims are secondary to increased production or are addressed through steps taken to increase agricultural output.

In economic terms, performance improvements achieved through any of these mechanisms can be realized by reducing system operating costs as well as by increasing the level of system outputs. The first two mechanisms--increased timeliness and serving additional area--typically involve added costs and the question becomes the relationship between costs and the additional benefits generated. Reductions in waterlogging and salinization can actually reduce net system operating costs when drainage and disposal costs are included in the consideration, since there is less need for artificial drainage facilities and less water to dispose of. Because little concern has been paid to the financial efficiency of system operations, however, and because water use efficiencies have generally been quite low, the possibility of reducing system operating costs while holding performance constant has received scant attention. This neglect can be expected to diminish as the move toward privatization begins to affect public sector concerns such as irrigation departments.

4.2 Hydrologic Efficiency

Overall system hydrologic efficiencies in surface irrigation systems in developing Asia in most cases vary between 25 and 40 percent This is in stark contrast to the situation in Taiwan, Israel and Japan where average overall efficiencies are said to exceed 60 percent, suggesting relatively large opportunities for significant increases in the effectiveness of existing water supplies.

The latter figure may not include the operational and seepage losses which occur in a large canal distribution system, however, even though water application may employ the latest technology. The Columbia Basin Project in the arid central region of Washington state irrigates 230,000 hectares of fertile farmland. At present about 60 percent of this area is irrigated by sprinklers, mostly center-pivot sprinklers, while in the remainder water is applied via furrows or level basins. All water used by the system is lifted several hundred feet from a large reservoir by huge pumps but distributed by gravity through partly lined main and secondary canals. Main regulators are equipped with electronic stage recorders, telemetry links to a central computer, and automatic control gates. Management is by farmer-controlled irrigation districts. Overall efficiency for this system is around 45 percent and has never been higher, in any given year, than 47 percent. It is somewhat difficult to imagine substantially higher efficiencies than these being generally achieved in large Asian systems where field crops are irrigated by surface application methods.

Many of the efficiency figures typically employed in assessing water use efficiency are derived from individual system evaluations rather than from basin-wide assessments. Unmeasured downstream recovery of "waste" surface water and extractions and recharge of groundwater can result in actual basin-wide efficiencies substantially greater than the nominal values for particular systems. For example, estimates of overall water use efficiencies for individual systems in the Nile Basin in Egypt are as low as 30 percent, but the overall efficiency for the entire Nile system in that country is estimated at around 70 percent. Given this efficiency, and the need to provide sufficient discharge in the Nile to prevent upstream migration of a salt front from the Mediterranean, the feasibility of significant additional savings of water

for application to other agricultural land through improved overall efficiency is not obvious. Similar observations can be made for the Mahaweli Project in Sri Lanka. The runoff from component System H, resulting from low overall efficiency of water use in that system, represents 40 percent of the supply for the system downstream which lies outside the official Mahaweli Project area (Levine, et al. 1988). This points up the real risk of overinvestment in new construction which simply shifts benefits from one location to another.

Irrigation in arid regions also requires that some water percolate through the soil profile to remove salts which are inevitably deposited in the crop root zone by the evapotranspiration process. This "leaching fraction" requirement, which can range upwards from a few percent to much larger values, means that 100 percent overall efficiency can never be achieved in such regions on a sustained basis, and ultimate achievable target efficiencies must be set at somewhat lower values.

In Maharashtra, India, many dug wells have been installed privately in hardrock areas within the commands of government canal irrigation systems. These wells obviously are recharged by seepage from the surface systems, but the extent of this recharge is unknown, and area served by the wells is not included in evaluations of the performance of the government systems. Improving these systems may result in improved economic efficiency, since pumping costs would be avoided by more careful management of water on the surface, but the gains in hydrologic efficiency will be far more limited that it would appear if recapture in wells is not considered. This type of conjunctive use will be discussed in more detail below.

Definitive estimates of the potential for increasing the effective water supply to expanded irrigated area requires site specific analyses, both to evaluate the real potential for increasing the supply and to identify the extent of irrigable land that could be served economically with the saved water, either through areal expansion or through increased irrigation intensities. However, it seems reasonable to suggest that there is less potential for improvement of water use efficiencies of existing systems than the nominal system-wise efficiency figures imply. Output gains from the two other mechanisms are potentially significant but difficult to estimate.

4.3 Improvement Programs

To realize potential output increases, it is usually necessary to mount systematic programs of intervention employing capital investment, policy changes at various levels, changes in operating procedures, and human resource development. System improvement programs have tended to fall into two categories, depending on the dominant element in the program. Rehabilitation projects have emphasized new investment to improve physical facilities and thereby increase output performance. Management improvement projects have emphasized the development and application of new operating procedures and staff training to accomplish this end. Below we touch briefly on each of these project types, along with two cross-cutting themes with significance for the future.

4.3.1 Rehabilitation Projects

When net returns to investment in new irrigation construction decline, it is natural to turn to rehabilitation projects as investment alternatives. Because such projects can take advantage of substantial sunk costs in existing systems, they are usually significantly cheaper than new construction projects. Sometimes the intent is simply to restore the project to its original design specifications. This approach is based on several assumptions which are usually difficult, at best, to substantiate (if they are examined)--(1) that the original design was flawless, (2) that water supply and demand patterns have remained relatively constant, and (3) that technology is unchanged from the time of the original design. Initial plans for rehabilitating the Gal Oya scheme in Sri Lanka in the early 1980s called for its restoration to original specifications, until it was discovered that an improvident typhoon had destroyed the original system drawings some years earlier.

More often, recognizing the need for changes in the design, systems are also "modernized" in the rehabilitation process. In this case a variety of changes in the project environment can be addressed and deficiencies in the original design can be corrected. Often, however, changes in the design, such as a shift from continuous delivery of water to a rotational delivery schedule at the tertiary level, are sufficiently radical that a whole new set of errors are committed in the process. One of the most powerful tools for making the redesign an improvement--drawing on the knowledge and experience of the farmers who have been using the system for 10 or 20 years--is seldom availed of in a systematic manner, and modernization planning is approached in much the same way as would be the design of an entirely new system. A common feature of modernization projects is augmentation of the system water supply and expansion of the commanded area, making them combinations of rehabilitation and new area development. Heavy investments in reducing canal losses through canal lining programs are also common, again focussing on making more water available to the system.

The employment of new technology in a rehabilitation project is a perplexing issue. Theory tells us that new technology is the way to improve the productivity of an economic enterprise and reduce its costs. And while there have been sweeping changes in irrigation technology in the West in the past 30 years, little of this development has affected Asian irrigation. The technology employed in a modern Indian canal irrigation system would, in most cases, be perfectly recognizable to a turn-of-the-century Indian irrigation engineer. A principal reason for this failure is that the most important developments in irrigation technology have occurred in the area of water application and not in the area of conveyance and distribution. Because of farm sizes, ownership patterns, and crop mixes and markets in the West, such technology has been readily adapted by western farmers and has a major impact on productivity.

The tremendous research effort expended over the past 40 years in the United States on determining crop water requirements and yield response functions is predicated on the assumption that water control at the field level is sufficiently precise to take advantage of this knowledge. Similar research has been replicated across Asia and continues to be a primary research focus in many countries. However in Asia where farms are smaller than U.S. farms

by 2 or 3 orders of magnitude, and irrigation schemes are often much larger than their U.S. counterparts, much of this research effort has been wasted, and there has been almost no adoption of the sprinkler and drip technologies now so common in the West. Here, the greatest need is for improved technologies for water conveyance, delivery, and allocation, and not for water application to crops. This requires a type of research which is vastly different than the agronomy-related research models which have been introduced from abroad, but which is little practiced anywhere in Asia. The International Program for Technology Research and Irrigation Development (IPTRID) which has recently been organized by the World Bank, is an attempt to stimulate this type of research. However, it has not, as yet, begun to wrestle with the fundamental question of the types of technologies which are most promising for such a research effort.

4.3.2 Management Improvement Projects

It has become abundantly clear that ineffective management of publicly-operated irrigation schemes is a fundamental cause of poor output performance and a factor which much be addressed directly if performance is to improve. The creation of the International Irrigation Management Institute (IIMI) in 1984, and its recent incorporation into the CGIAR system, affirms this. Projects developed under this heading often attempt to achieve greater water use efficiencies by tightening management procedures, to increase equity of water distribution across the command, and to improve timeliness of deliveries. Management improvement projects are usually more closely linked conceptually to project outputs, through the mechanisms outlined earlier, than are rehabilitation projects, since management is always an intervening variable between system hardware and system outputs.

Two broad thrusts can be found in the management improvement projects mounted over the past 30 years. The first of these focussed on "On-Farm Water Management" and had its roots in the research methodologies of the land-grant colleges of the western United States. It was unfortunately named, since it focussed on water management not literally "on the farm", but rather on groups of farms which might have corresponded in size to a U.S. irrigated farm--and hence the name. Its most important early manifestation was the long-running project assisted by Colorado State University in Pakistan to improve the water use efficiency and distributional equity in an irrigation system along Pakistan's 70,000 watercourses. This work was subsequently extended on a large scale to India and Egypt and to a variety of other locations through short courses and problem assessment exercises conducted by CSU staff members and others. A fundamental premise of this work was that the primary problems of efficiency and equity in an irrigation system existed at the tertiary unit level where farmer-management typically predominates, and diagnostic efforts and solutions were largely targeted at that level. Typically, solutions involved watercourse realignment and lining, improved small-scale water control structures and rotational plans, and precision leveling of irrigated fields.

In response to this tertiary-level focus and in recognition of its limitations, a second approach evolved which emphasized the management of the main system. The approach taken by this group argued that farmers did a reasonably good job of managing water within the

constraints they faced--namely unreliable and often inadequate supplies from the main system. Since main systems in larger schemes are usually run by public irrigation bureaucracies, emphasis was on improving the performance of the irrigation bureaucracy and the facilities it operated. Robert Chambers (1980, 1984) has probably been the most eloquent spokesperson for this perspective. Means employed involved staff training, farmer involvement, and changes in operating rules coupled with selective physical improvements to main system facilities. It should be clear that these two approaches are complementary rather than exclusive, though one or the other may be most appropriate in a particular circumstance.

Twining through these two approaches to improving system output performance are a pair of cross-cutting themes--one is well-established and of continuing relevance, and the other seems likely to grow considerably in importance over the remainder of the decade. The first is the practice of involving farmers more directly and intimately in both the processes of system management and system improvement. "Farmer participation" has by now become virtually its own discipline, and a large volume of conceptual papers, case studies, methodology manuals, and check lists are available. It is applied both as a means of directly improving tertiary level water management and maintenance of system facilities, and in conjunction with activities aimed at main system managers, as a way of building a grass-roots structure which can link with the irrigation bureaucracy to facilitate improved management of whole systems. The most celebrated examples of this approach come from the Philippines (Korten and Siy 1991; delos Reyes and Jopillo 1986), but experience now exists in a large number of countries in both Asia and Africa. Although a difficult process to initiate and sustain, it has shown enough promise in a variety of settings to insure that it will continue to be an important tool in performance improvement efforts in the years to come. A challenge is to insure that the linkage between methods of increasing farmer involvement in system operation remain firmly connected to the objective of improving the quality of irrigation service and increasing system agricultural outputs. Although arguably there is benefit in simply having farmers more involved in decisions affecting them, the case for farmer participation becomes substantially less compelling if the linkage with productivity cannot be firmly established. There is a strong need for additional work examining this linkage.

The second theme is one that has received relatively less attention but which now appears to be critical for long-term progress in improving system performance. Just as changes in available technology alone are insufficient to generate significant improvements in irrigation performance, likewise it is becoming increasingly clear that management innovations, by themselves, will not suffice for the task. The "pilot effect," wherein seemingly successful management innovations wither and die once the external resources supporting them are withdrawn, is far too common. Attention is beginning to shift to the sectoral policies and institutional forms which shape the operation of irrigation agencies. Examination of the personal and institutional rewards and incentives which operate within public irrigation bureaucracies suggest that more fundamental changes in policies and institutions are needed to permit what A. Sundar calls "the will to manage" to emerge.

Tools and mechanisms suggested for use in this area include shifting the mode of organization of the irrigation agency from a regular branch of a line government ministry or department to an independent or quasi-independent form, applying financial viability criteria to irrigation agencies, profit-sharing plans for employees, franchising the right to operate publicly-constructed irrigation facilities, and strengthened accountability mechanisms as by providing for farmer oversight of operating agencies. A common thread in many of these suggestions for reorganization is the use of financial incentives and criteria in judging institutional and individual performance. If irrigation service fees can be made the primary **variable** source of agency funding, then a powerful accountability mechanism is established which will serve as the armature for a variety of different approaches and programs designed to improve operational performance. Note that it is not necessary for farmers to bear **all** of the costs of irrigation development and operation for these mechanisms to work, but only that agency income varies in proportion to farmer payments.

4.3.3 Impacts of Improvement Projects: A Review of Evidence

Case-studies containing economic evaluations of rehabilitation have proliferated in recent years. Zhi (1989) reports results of rehabilitation and management reform of the Zhanghe irrigation scheme in South China in terms of 12 techno-economic indices of performance. Following rehabilitation, irrigation efficiency increased from 48 percent to 60 percent and rice yields and economic benefits increased by 48 percent and 40 percent respectively. The yield and economic indicators, however, did not control for other sources of productivity change over the eight-year evaluation period and probably overstate the impacts of the rehabilitation.

In another promising report, Sakthivadivel (1987) states that the increased conveyance and field application efficiencies produced by the Periyar-Vaigai rehabilitation project in South India resulted in water saving of 28 percent. Pilot studies indicated that yields increased by 25 percent and the incremental income for a 1.2 hectare farm was expected to be $290. Using benefit-cost analysis, Olivares and Wieland (1987) estimate the IRRs for three rehabilitation projects--the Sudan Blue Nile Pump Scheme, East Vermion in Greece, and a rehabilitation project in Peru--as 32 percent, 18.5 percent, and 18 percent respectively. In a highly promising approach based on selective rehabilitation, Sinha (1991) recently designed low-cost ($125-$440/ha) improvements for nine irrigation systems in the Indian state of Bihar based on careful studies of each system. Estimated benefit/cost ratios range from 1.8 to 4.5, averaging 2.9.

However, other case study results are not as encouraging. Murray-Rust and Rao (1987) and Abeysekera (1984) report that though the Tank Irrigation and Modernization Project in Sri Lanka led to an overall increase in productivity, the widely fluctuating water supply conditions both during and after the project and a lack of good pre-rehabilitation data on income make it hard to know what increases were specifically due to rehabilitation and which to other factors, a problem common to many other studies also. For the Gal Oya project, Wijayaratna (1987) states that rehabilitation has had a limited impact on production. It was found that non-water constraints were responsible for nearly 60 percent of the foregone crop yield. Recent *ex post* evaluations of rehabilitation projects in the Philippines and Thailand (World Bank 1990a) and

Mexico and Morocco (World Bank 1990b) also show disappointing results (low WUEs, low yields and low cropping intensities) with the exception of the Doukkala I and II projects in Morocco. Rosegrant, et al. (1987), find low returns, (5-9 percent) to three large-scale rehabilitation projects in the Philippines.

The evidence on the impact of management interventions to improve water use efficiency and boost production and income is highly mixed. Some of the earliest field studies on the impact of improved water management and distribution were carried out in the Philippines in the mid-1970s. Experiments conducted in the Upper Pampanga River Project by Wickham and Valera (1978) revealed that efficiency of combined water conveyance and use along one lateral canal increased to over 90 percent when water deliveries were shifted from a continuous basis to a rotation, compared to only 68 percent in the traditionally managed areas. However the yield (and the mean water use efficiencies) in the rotational areas were only marginally higher than in the continuous areas, and in neither case was the difference statistically significant. This slight advantage was negated by the fact that the additional costs of the rotational model were much higher than those for the continuous model.

Analyzing irrigation performance in three national gravity irrigation systems (Sta. Cruz, Angat, and Peñaranda), Miranda and Levine (1978) concluded that there is some evidence that WUE in the dry season was higher in areas served by farm-ditch rotational irrigation, but cautioned that these results were only indicative because they were based on a limited set of sites. For the Lower Talavera River Irrigation System (LTRIS), research by Early (1980) indicated that the efficiency of the sample lateral increased to 60 percent for both wet and dry season in 1977-78, compared to 43 percent and 51 percent in the 1975-76 wet and dry seasons. Although yield increases were reported, an inadequate water supply during the base year (1976) was partly responsible for the poor yields recorded in that year. A subsequent study on the LTRIS (Small and Chen 1986) estimated the potential increase in production from further improvements in water allocation to be negligible.

Because of the difficulties involved in carrying out reliable before and after studies of improvement investments and interventions, simulation modeling has been widely used to assess impacts of actual and proposed changes. Among the studies that use simulation techniques to estimate the benefits from system management, O'Mara and Duloy (1984) report gains of 17 to 20 percent in agricultural output and 14 to 16 percent in employment from more efficient joint management of surface and groundwater in the Indus basin of Pakistan. Using an integrative simulation model to simulate alternative water management strategies for the state of Punjab in Pakistan, Johnson and Reuss (1984) indicate that a change in the current canal closure schedules could increase possible returns by $20 to $30 per hectare. Chaudhry and Ali (1989) use a simulation model to trace out the effects of various (exogenous) O&M investment scenarios on output, prices, and incomes and conclude that increases in agricultural production can be realized by increasing O&M investment in canals and private tubewells. Kelley and Johnson (1989) evaluate water distribution rules in E. Java using simulations and find that proper implementation of the rules could result in an incremental increase in water availability by 45 percent, and incremental net returns of 28 percent.

Simulation studies evaluating various tank modernization options in Tamil Nadu, India are detailed in Govindasamy (1991), Govindasamy and Balasubramanian (1990), Govindasamy and Palanisami (1990), Palanisami (1990) and Palanisami and Flinn (1988). Results indicate that sluice and rotation management had the highest returns but there exist tradeoffs between productivity and equity criteria, thus highlighting the importance of the socio-political process in determining actual rehabilitation choices. In a simulation analysis of rotational irrigation and rehabilitation of four irrigation systems in the Philippines, Rosegrant (1990) found highly variable returns. Internal rates of return for rotational irrigation varied from zero to 24 percent, and rates of return to rehabilitation varied from zero to 11 percent.

If evidence on effectiveness of rehabilitation and management improvement efforts is mixed and somewhat contradictory, then information on output impacts of farmer participation and sectoral policy and institutional reform interventions is virtually non-existent. Svendsen, et al (1991) in reanalyzing data collected by delos Reyes found little measurable impact on productivity of the turnover of four small Philippine systems to farmers for management on productivity, though the costs to the irrigation agency did decline significantly. Uphoff has argued that the participatory approach applied in the Gal Oya scheme rehabilitation in Sri Lanka provided very large returns on investment, but the participatory effort there was a small part of the whole rehabilitation project.

An assessment of the impacts of policy changes in the Philippines which led to a financially autonomous irrigation agency show marked reductions in the cost of operating the country's large-system portfolio taking place, with no measurable decline in system agricultural performance attributable to the change. The assessment also showed, that after controlling for rainfall and available water supply, that sample systems were able to irrigate a statistically significant 13 percent more land after the irrigation agency was made to operate as a financially autonomous, quasi-independent agency (Svendsen 1992).

4.4 Implications

Given the wide variations in the success of rehabilitation and management interventions in increasing production and income by improving irrigation system efficiency, can general conclusions be drawn? Perhaps the only simple conclusion is the importance of selectivity in project selection and design. Many rehabilitations that have been undertaken are large-scale, capital intensive projects which aim at a thorough remake of the system. These investments are subject to the same type of rent-seeking, delays, and cost overruns that characterize much new system construction. Now, because international lending levels for irrigation have fallen, there may be less pressure on lending agency personnel to design and promote such intensive and comprehensive interventions in order to keep lending levels up, providing greater opportunity to experiment with more selective lower-cost rehabilitations.

Innovative thinking and research is needed to identify appropriate systems for intervention, to select the appropriate intervention points within these systems, and to identify low-cost rehabilitation options to implement at these intervention points. Barriers between

rehabilitation projects and management improvement projects must be knocked down and a full range of possible changes considered for a given project, together with a careful consideration of their interrelationships.

There is need for a new mode of project appraisal and design, tailored for improvement work in existing systems. Extensive involvement of farmers must characterize this process, as farmers have valuable knowledge regarding deficiencies of the existing system and its likely reactions to changes in system configuration and operating rules. The mode of interaction between project engineers and economists must also change. Rather than being a sequential process of technical design followed by economic evaluation, project development should consist of continuous interaction as the design evolves, so that the net benefits from individual project components can be evaluated and components added or deleted based on their contribution to total project benefits. Micro computers make such repetitive interactive design work entirely feasible.

There is a need for far greater rigor in our approaches to assessing the impact of our interventions. Such approaches must involve simulation or statistical techniques for controlling for the effects of variables such as rainfall, available water supply, and fertilizer use in assessing impacts, so that change can be attributed to the correct source. Better data is, of course, needed for this in many cases, especially pre-project data. However, sponsors of improvement projects need to manifest their curiosity about the results of their projects in support for studies which would develop better methodologies for assessing their impacts. Of considerable utility would be work separating measures of irrigation performance from those involved in assessing irrigated agricultural performance, where many more confounding factors are involved. Finding ways to assess directly the quality of irrigation service and to make explicit and quantitative the linkages between quality of irrigation service and agricultural production would constitute a major step forward in tracing the causal linkages between irrigation improvement interventions and agricultural output impacts.

There is also a need to seek out promising technologies which have been developed in recent years and systematically examine their potential for improving irrigation performance, with special reference to the performance of water allocation and distribution systems. This must be done in conjunction with management research, since effective technologies will not be adopted by individual farmers but by bureaucratically-organized agencies which do not operate in a market environment.

Finally there is a powerful need to examine sectoral policies which affect the functioning and performance of public agencies which manage irrigation systems, in addition to our traditional concern with policies which affect farm decision-makers. It seems likely that efforts to implement sustained improvements in system performance through changes in operating rules and procedures will peak at relatively low levels without more fundamental changes of this nature. Political and economic winds that currently blow throughout the world should favor reforms of this type, even in countries where such changes would have been unthinkable just a few years ago.

In sum, while the generalized high level of benefits expected by some observers from performance improvement activities are not realizable, productive investments to improve irrigation performance can be made and significant gains achieved. Success will involve an intelligent selective approach--one based on a menu of choices which spans a wide range of possible interventions, flexible and broadly participatory design approaches, and attention to all aspects of the policy environment which surrounds irrigated agriculture.

5. PRIVATE INVESTMENT IN IRRIGATION

The discussion of irrigation trends in India showed the importance of rapid growth in tubewell irrigation, which is overwhelmingly privately developed, within the overall irrigation sector there. In more general terms, the expansion of private sector tubewell irrigation in India, Pakistan, and Bangladesh is the most successful example of private sector irrigation in the developing world.

Private tubewells have grown most rapidly in areas with reasonably good roads, research and extension systems, and where credit and electric or diesel energy is accessible. It should also be noted that private tubewells have largely developed in and around the command areas of large surface irrigation systems. Seckler (1990) notes three reasons for this: (1) deep percolation losses from the surface systems recharge the aquifers for tubewells; (2) the tubewells are often used together with surface irrigation water, which lowers pumping costs and concentrates these costs in periods of highest marginal returns; and (3) the tubewells ride piggyback on the infrastructure created for the surface systems.

The externalities produced by canal irrigation projects are widely recognized. Shah (1991) notes that the increasing awareness of the diseconomies imposed by waterlogging and the consequent build-up of salinity in crop root zones has contributed in substantial measure to the growing disenchantment with major irrigation projects in India. External economies of canal irrigation are also important, and benefits flowing from increased productivity of private wells within canal commands can help to justify further investment in canal projects. Appropriate conjunctive use of ground and surface water can both lessen the diseconomies and maximize the positive externalities of canal irrigation.

Conjunctive use of surface and groundwater has several important aspects, including (1) the use of wells as an on-demand irrigation system, when canal water is inadequate or unreliable, to reduce moisture stress and maximize irrigated crop yields; (2) pumping of groundwater into the canals to augment the canal water resources, lower the water table, and reduce salinity; and (3) the potential for viewing a canal command and its imbedded tubewells as an integrated system and jointly optimizing use of canal *and* groundwater resources. One additional feature which is very important in the Gangetic basin is the capacity of alluvial aquifers to serve as storage media for highly variable river flows. The flat topography of much of Eastern India and Bangladesh affords little opportunity to build conventional storage reservoirs of the type that exist in Northern India and Pakistan. Shallow groundwater storage is a very attractive alternative with no evaporative losses and easy and decentralized access for irrigators.

Despite the apparent benefits arising from expansion of groundwater use, there has been considerable criticism arising from the view that the lumpiness and relatively high cost of tubewell investment will preclude investment by small farmers, and will subject small farmers to monopolistic prices for the use of water. However, Chaudhry (1990) shows that, in Pakistan, this has not happened. Instead, the development of a hire market in tubewell services has

stimulated the emergence of a new entrepreneurial class in the rural areas. Inequalities in rural income in areas of high tubewell penetration are dwindling and benefits emanating from new technology are widely shared with small and medium farmers.

Similarly, Shah (1991) details the development of highly competitive water markets in India. Intense competition among sellers contains arbitrary or collusive behavior and ensures access to groundwater by land-poor farmers who cannot afford to invest in their own wells. Groundwater prices are responsive to changes in energy costs and to the availability of canal water. On equity as well as efficiency grounds, these highly developed groundwater markets have attractive and socially desirable properties.

Rapid development of the private tubewell sector, successful development of markets for water, and the underexploited positive externalities between canal and tubewell irrigation all indicate the potential for considerable expansion of this sector in Asia. What should be the government role be in this expansion? The highly successful deregulation and privatization of the tubewell sector in Bangladesh in the mid-1980s suggests that the major role of the government is as a facilitator, through provision of public goods, and a regulator, rather than as an active participant.

More specifically, Wyss enumerates the following factors contributing to the success of private sector irrigation investments: "legal access to an unappropriated resource, strict enforcement of legal rights, institutional development of the domestic capital market, socioeconomic conditions favoring cooperative investments, legal protection for private investments, relatively low cost of capital, a high ratio of rural labor to arable land, an infrastructure that permits relatively low-cost access to larger markets, and policies that do not shift the internal terms of trade against agriculture."

Governments should seek to reduce subsidies on irrigation equipment, credit, and energy which tend to encourage high-cost and inefficient investments and which create continuing pressure on ordinary budget resources of the government. To the extent that distortions exist throughout the economy, though, such reductions must be made carefully to avoid exacerbating existing problems of unfavorable internal terms of trade for agriculture or creating new ones. Most appropriate initial reductions in subsidies would be on infrastructural services, such as electricity, which affect wide segments of the economy. More realistic rates for services such as electricity will also have a more powerful role in regulating water resource use than will a reduction in direct capital subsidies on tubewell development. The key role of the government in the sector should be to provide the appropriate institutional and infrastructural environment within which private investment can make appropriate choices. To the extent that availability of services such as reliable power supplies in rural areas constrains groundwater development, governments should invest to ease these constraints.

6. POLICY IMPLICATIONS

It is difficult to derive general conclusions on irrigation investment and management strategies. Even broad strategies tend to be country-specific, and implementable decisions quickly become region and project-specific. Nevertheless, the following is an attempt to generalize from the preceding discussion.

First, the substantial cutback in public investment on irrigation during the 1980s appears to be an appropriate response to declining world rice and wheat prices and the rapidly increasing capital costs of irrigation. Rapid expansion of inefficient, high cost public irrigation to expand production and keep prices low would be self-defeating. If capital costs are passed on to farmers (which governments have historically been unable or unwilling to do) the costs will be capitalized into food prices; if costs are subsidized by the government from general revenues, consumers will pay out of one pocket what they are saving in the other pocket from lower food prices.

Nevertheless, there appears to be merit in arguments that, due to the endogeneity of world prices and asymmetric risk concerns, a moderately higher shadow price for rice and wheat could be utilized in evaluation of irrigation (and other) investments. These modified shadow prices would reflect the probable long term effects of the reductions in irrigation investment over the past few years. If shadow prices were revised slightly upward, the portfolio of cost-effective new irrigation projects would increase somewhat compared to current levels, moderately boosting expenditures on new irrigation, rehabilitation, and other irrigation improvement options. Development of policy models to analyze the investment-production-price relationships for major commodities should have high payoffs in improving investment decision-making.

Selective investment in irrigation rehabilitation, management reforms, and other interventions to improve the efficiency and performance of irrigation systems should continue to have an important role in future development in Asian irrigation. However, the rates of return, and aggregate production and income payoffs of these investments do not appear to be as high as many observers have estimated. The tendency toward high cost rehabilitation to reconstruct and modernize systems from the dam to the farmers' fields should be avoided. Careful identification of systems to be rehabilitated and selection of high-payoff points of intervention within the systems will improve the cost-effectiveness of these interventions. Improved impact assessment methodologies could yield large benefits by better identifying cost-effective intervention.

Expansion of private investment in irrigation, particularly tubewells, is very promising. While the government role in encouraging private investment should be indirect, consisting primarily of sustenance of an appropriate legal/institutional environment, and provision of adequate public goods and services, it is nevertheless critical to expansion of private investment. Targeted investments in public goods, such as energy and roads, which can facilitate the

expansion of conjunctive use of tubewells and canal irrigation, should be particularly productive due to the largely unexploited positive externalities arising from conjunctive use.

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Table 1 **Rice: Annual Growth Rates of Area, Production, and Yield, Asia, 1957/59-1988/90**

Countries/ Regions	1957/59-1988/90	1957/59-1965/67	1965/67-1973/75	1973/75-1981/83	1981/83-1988/90
Total Asia					
Area	0.73	0.85	1.09	0.24	0.25
Production	3.08	2.60	3.37	3.09	2.16
Yield	2.36	1.74	2.27	2.86	1.91
Southeast Asia					
Area	0.93	1.73	0.35	1.51	0.72
Production	3.24	3.17	3.29	4.28	2.29
Yield	2.32	1.46	2.94	3.22	1.57
South Asia					
Area	0.89	1.26	0.61	0.88	0.25
Production	2.33	3.13	1.63	2.57	2.31
Yield	1.45	1.89	1.02	1.71	2.03
China					
Area	0.52	-0.58	2.25	-1.07	-0.38
Production	3.55	2.62	3.92	2.98	1.25
Yield	3.03	3.21	1.68	4.06	1.63
India					
Area	0.67	1.21	0.74	0.46	0.34
Production	2.49	1.95	2.90	2.22	3.62
Yield	1.81	0.74	2.15	1.57	3.23

South Asia includes Bangladesh, Nepal, Pakistan, and Sri Lanka, excluding India.

Southeast Asia includes Burma, Indonesia, Kampuchea, Laos, Malaysia, Philippines, Thailand, and Vietnam.

Source of data: World Rice Statistics, 1990, IRRI.

Table 2 Wheat: Annual Growth Rates of Area, Production, and Yield, Asia, 1961/63-1987/89

Countries/Regions		1961/63-1987/89	1961/63-1965/67	1965/67-1973/75	1973/75-1981/83	1981/83-1987/89
Total Asia	Area	1.50	0.02	2.41	1.58	0.29
	Prod	5.96	6.24	6.46	5.99	2.96
	Yield	4.46	6.22	4.07	4.41	2.69
Southeast Asia	Area	1.62	7.93	-3.72	4.48	2.04
	Prod	4.25	7.49	0.86	3.74	4.78
	Yield	2.67	0.36	4.63	-0.77	2.79
South Asia	Area	2.15	1.88	1.65	3.36	1.03
	Prod	5.36	1.55	6.59	6.55	2.07
	Yield	3.22	-0.35	5.03	3.19	1.06
China	Area	0.86	0.24	1.19	0.62	0.31
	Prod	6.50	11.79	5.45	6.26	3.17
	Yield	5.63	11.49	4.25	5.66	2.88
India	Area	2.65	-0.93	5.26	2.56	0.13
	Prod	6.30	0.06	10.07	6.02	3.03
	Yield	3.66	0.97	4.89	3.47	2.92

Southeast Asia includes Burma, Indonesia, Kampuchea, Laos, Malaysia, Philippines, Thailand, Vietnam.

South Asia includes Bangladesh, Nepal, Pakistan, and Sri Lanka, excluding India.

Source of data: FAO Production Data.

Table 3 Irrigated Area of the World, 1988

Region	Total Area	Arable	Irrigated	% Arable Area Irrigated
WORLD	13,069,253	1,373,404	228,672	17
Asia	2,678,660	420,872	143,417	34
North and Central America	2,131,804	267,095	25,809	10
Europe	472,053	126,139	17,297	14
Africa	2,963,914	167,934	11,146	7
South America	1,752,926	115,988	8,755	8
Australia	761,793	46,806	1,850	4
Rest of the world	2,308,103	228,570	20,398	9

Source: FAO Production Yearbook.

Table 4 **Average Annual Growth Rate of Irrigated Agricultural Area in Asia, 1960-88**

	Total	South Asia	Southeast Asia	East Asia
	percent			
1960-88	1.7	1.9	2.7	1.1
1960-65	2.0	1.8	1.6	2.2
1965-70	2.5	2.9	1.2	2.4
1970-75	2.0	1.8	2.8	2.1
1975-80	2.0	2.8	3.6	1.2
1980-85	1.2	1.8	4.1	-0.3
1985-88	0.4	0.1	1.5	0.3

Source of basic data: FAO.

Note: East Asia includes China, Hongkong, Japan, DPR Korea, Korea Republic, Macau and Mongolia. Southeast Asia includes Brunei, Burma, Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand, and Vietnam. South Asia includes Bangladesh, Bhutan, India Sri Lanka, Maldives, Nepal, and Pakistan.

Table 5 Average annual lending and assistance for irrigation by World Bank, Asian Development Bank, U.S. Agency for International Development, and Japanese Overseas Economic Cooperation Fund, to South and Southeast Asia constant 1980 prices

Year	Lending and Assistance to Irrigation				
	World Bank (1)	ADB (2)	OECF (3)	USAID (4)	Total of (1)+(2)+(3)+(4)
	$ million				
1969-70	-	53	6	-	-
1971-73	-	69	7	-	--
1974-76	668	84	16	-	
1977-79	981	219	33	68	1,301
1980-82	888	253	46	71	1,258
1983-85	680	162	69	69	980
1986-87	405	144	21	38	608

Sources: World Bank, ADB, OECF, USAID.

Table 6 **Average annual lending and assistance for irrigation in South Asia by World Bank, Asian Development Bank, U.S. Agency for International Development, and Japanese Overseas Economic Cooperation Fund, constant 1980 prices**

Year	Lending and Assistance to Irrigation				
	World Bank (1)	ADB (2)	OECF (3)	USAID (4)	Total of (1)+(2)+(3)+(4)
	$ million				
1969-70	-	18	0	-	-
1971-73	-	8	0	-	-
1974-76	349	32	0	-	-
1977-79	514	85	4	50	653
1980-82	651	100	15	54	820
1983-85	533	74	10	68	685
1986-87	317	48	3	29	397

Sources: World Bank, ADB, OECF, USAID.

Table 7 **Average annual lending and assistance for irrigation in Southeast Asia by World Bank, Asian Development Bank, U.S. Agency for International Development, and Japanese Overseas Economic Cooperation Fund, constant 1980 prices**

Year	Lending and Assistance to Irrigation					
	World Bank (1)	ADB (2)	OECF (3)	USAID (4)	Total of (1)+(2)+(3)	Total of (1)+(2)+(3)+(4)
	$ million					
1969-70	-	35	6	-	-	-
1971-73	-	61	7	-	-	-
1974-76	319	52	16	-	387	-
1977-79	467	134	29	18	630	648
1980-82	237	153	31	17	411	438
1983-85	147	87	59	5	293	298
1986-87	88	96	18	9	202	211

Sources: World Bank, ADB, OECF, and USAID.

Table 8 Index of Average Annual Public Expenditures for New Irrigation Construction, 1976-80=100

Time Period	India	Indonesia[a]	Philippines[a]	Sri Lanka	Thailand
1971-75	60	20	25	37	99
1976-80	100	100	100	100	100
1981-85	94	192	125	92	151
1986-90	80	170	45	55	109

[a] For Indonesia, and the Philippines, the successive time periods are 1969-73, 1974-78, 1979-83, 1984-88, 1974-78=100.

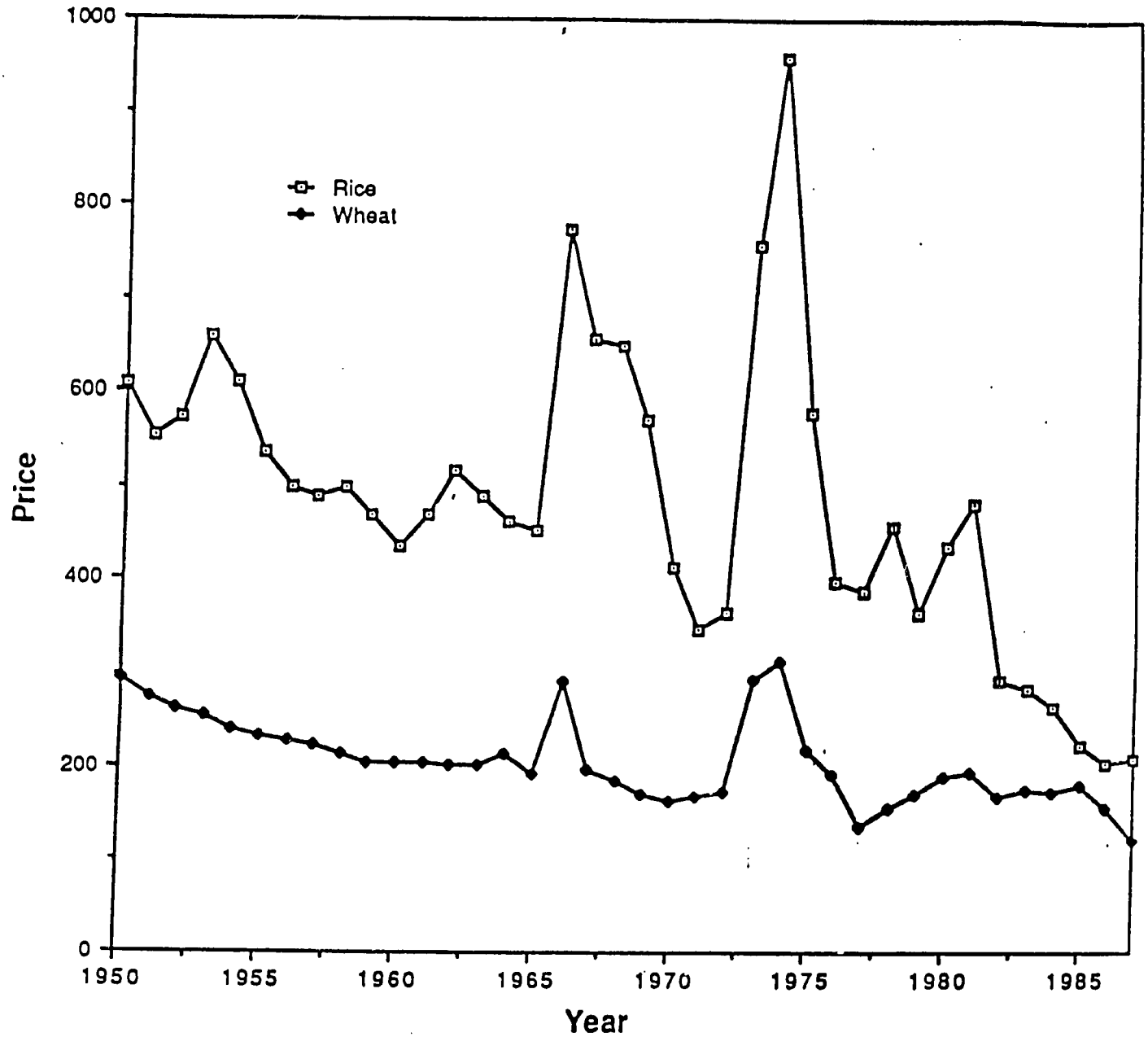
Sources: Computed from Gulati; Rosegrant and Pasandaran; Azarcon; Aluwihare and Kikuchi; and Rosegrant and Mongkolsmai.

Table 9 Real Capital Costs for Construction of New Irrigation Systems, 1966-88

Year	India (1988 prices)	Indonesia (1985 prices)	Philippines (1985 prices)	Sri Lanka (1986 prices)	Thailand (1985 prices)
	US$/ha				
1966-69	2698	1521	1613	1470	1419
1970-74	2368	1681	1882	2056	2584
1975-80	1656	3187	2263	2909	2366
1981-85	4033	3283	2688	5288	2276
1986-88	4856	4096	na	5776	2812

Sources: Computed from Gulati; Rosegrant and Pasandaran; Azarcon; Aluwihare and Kikuchi; and Rosegrant and Mongkolsmai.

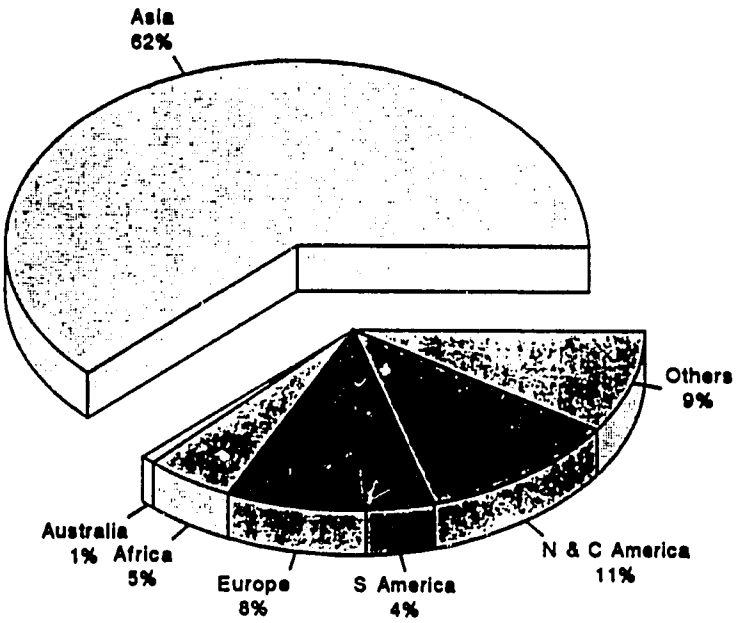
Figure 1 Constant 1980 Prices (US$/T FOB) of Rice and Wheat, 1950-87



Note: FOB=free on board. Prices deflated by Manufacturing index. Rice price is for 5% brokens, milled, FOB Bangkok. Wheat price is for Canadian No. 1 Western Red Spring 13.5%, in store Thunder Bay, domestic, from 1985 St. Lawrence export.

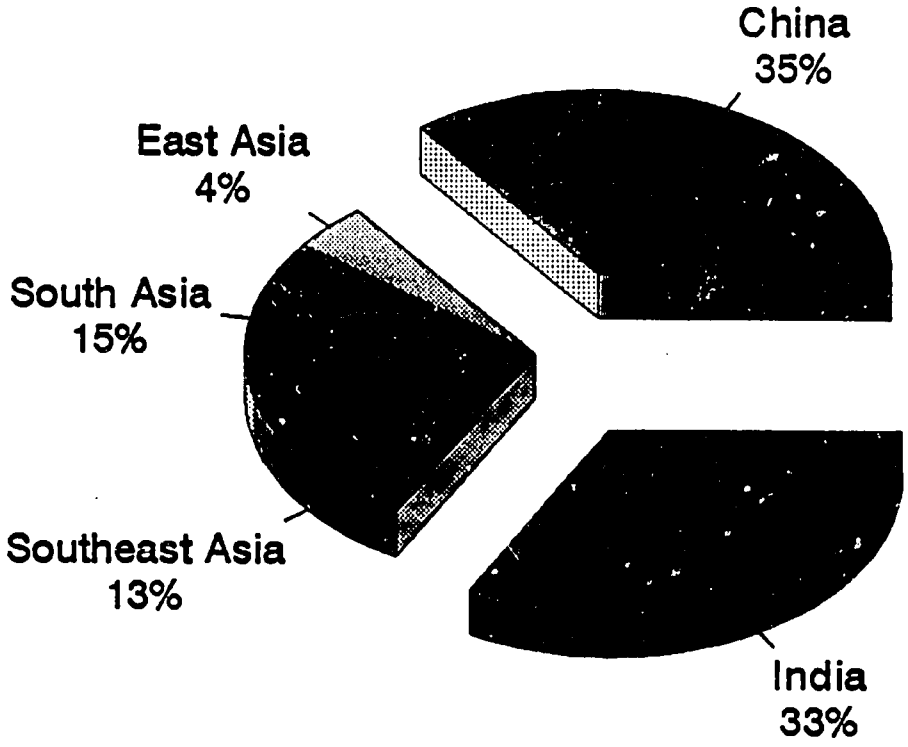
Source: World Bank and USDA.

Figure 2 Distribution of the World's Irrigated Area by Region, 1988



Source: FAO Production Yearbook.

Figure 3 Distribution of Irrigated Area in the Asian Region, 1988



Source: FAO Production Yearbook.

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APPENDIX

IRRIGATION INVESTMENT TRENDS IN FIVE CASE STUDY COUNTRIES

1. India

As was shown in the introduction of this paper, growth rates in productivity and output of rice in India continued to increase in India in the late 1980s, and there was a relatively modest decline in growth of wheat yields during this period compared to other regions in Asia. The relatively rapid yield growth in India is partly due to the pattern of regional growth. In rice, for example, the Northern and Western regions of India were the earliest adopters of the modern seed-fertilizer technology, and these regions showed some decline in yield growth during the 1980s. However, the relatively late-adopting Southern rice regions entered a more rapid growth in the 1980s, as the modern rice technology was more fully adopted and utilized (Sarma and Gandhi, 1990). Strong growth in the 1980s in late-adopting regions helped to maintain national average yield growth. In addition, levels of public irrigation investment, and rates of growth in irrigated area were maintained well into the 1980s, unlike in other countries, where cutbacks began at an earlier period; and there was rapid growth in private investment in tubewell irrigation.

Since central planning began in 1950, net irrigated area in India has expanded at a compound rate of 2.2 percent per year (Appendix Tables 1-2). This overall figure, however, masks some interesting shifts in the composition of this growth. Over the period 1950-1980, area under canal irrigation grew at a nearly constant rate of about 1.95 percent per year, but then declined sharply to 1.1 percent growth per year in the 1980s (Svendsen, 1991). The area under tank irrigation has declined steadily since 1960. The most interesting trend is the very rapid growth of wells, particularly tubewells. Nearly 80 percent of these wells are privately owned. Area under well irrigation grew at 5.5 percent during 1960-70 and 4.3 percent during 1970-80, before declining to a still rapid 2.9 percent during the 1980s. By 1973/74, the area under well irrigation had surpassed the area under canals, and by 1986/87 was 33 percent greater. Aggregated across all types of irrigation, there was a decline in the growth rate of total irrigated area in the 1980s.

Public expenditure on irrigation also declined in the 1980s. Based on Gulati (1991), expenditures in the fifth plan (1980-85) were on average about 10 percent less than the peak levels, and anticipated expenditures in 1985-90 were nearly 25 percent lower. Appendix Table 3 shows investment in irrigation in India by economic plan period since 1950. The expenditure trends show a strong build-up in invetment on capital construction through the end of the 1970s, with a peak annual average expenditure of Rs crores 433.5, followed by a moderate decline in expenditures in the 1980s.

2. Indonesia

This section, drawn from Rosegrant and Pasandaran (1990), reviews trends in irrigated area development in Indonesia. The two main sources of data on irrigated area in Indonesia are

the Central Bureau of Statistics (CBS) and the Directorate General of Water Resources Research (DGWRD) of the Ministry of Public Works.

CBS reports two types of data on irrigated area: (a) irrigated and wetland paddy area harvested; and (b) area of wetland by type of irrigation and number of paddy plantings per crop year. The first of these sources overstates irrigated area harvested, because it includes wetland, non-irrigated paddy in the same reporting category as irrigated paddy area. The latter data provide better detail, but because they are reported on an area planted basis as compared to area harvested, it is not directly comparable to the first source. Nevertheless, both of these data series provide a useful basis for comparison of trends with the data provided by DGWRD, which reports irrigated area on a physical service area basis.

The CBS data on area harvested for irrigated and wetland paddy, dryland paddy, and total paddy, and yield and production of paddy in Indonesia, 1969-87, are given in Appendix Table 4. Total irrigated and wetland area harvested has grown at a rate of just under 1.7 percent per year since 1969. The rate of increase has been about 1.3 percent on Java and 2.2 percent off-Java. The rate of growth in irrigated and wetland area has been relatively steady throughout this period, with nearly equal rates of growth before and after 1980. Thus there is no general pattern of decline in growth in irrigated area in Indonesia. Irrigated and wetland area occupied 82 percent of total paddy area harvested in 1969, and 89 percent in 1987. As noted above, these figures overstate the actual proportion of irrigated area, because they include rainfed lowland areas and tidal and inland swamp irrigation. If the latter areas are deducted from irrigated and wetland areas, irrigated area represented about 68 percent of total paddy area harvested in 1985.

Appendix Table 5 presents physical service area in Public Works irrigation systems as compiled by DGWRD. Time series data on the area irrigated in village systems is not available. Total irrigated service area increased at a rate of 2.6 percent per year from 1969-71 to 1985-87. The growth rate in service area was very rapid off-Java, 3.7 percent per year, compared to only 0.5 percent on Java. The growth rate in potential service area was higher in the 1980s, 2.6 percent per year compare to 1.8 percent per year prior to 1980. This reflects the heavy investment expenditures in the late 1970s and early 1980s described below.

Irrigation development expenditures and physical area completions. Irrigation development expenditures and area completions by Repelita, or five-year development plan, 1969/70 to 1988/89 are summarized in Appendix Tables 6 and 7. The irrigation investment program grew dramatically through the first three Repelitas. Real expenditures in the third plan were more than five times larger than in the first plan. However, expenditures declined by almost 20 percent between Repelita III and Repelita IV. The decline in actual expenditures in the fourth plan, despite higher planned expenditures, is discussed below.

As shown in Appendix Table 6, rehabilitation received the largest share of expenditures in the first plan, over 40 percent of the total. Although declining in relative importance, rehabilitation expenditures increased substantially in absolute terms through the third plan, before a reduction in the fourth plan. Over the course of the first three plans, expenditures on

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construction of new irrigation systems increased rapidly and received the largest aggregate share of expenditures, averaging 38 percent of expenditures during the first three Repelitas. Real expenditures on new construction increased nearly ten-fold between the first and third plans. The swamp and tidal irrigation development program, which received nearly 30 percent of expenditures in the first Repelita, has declined in relative importance to about 5 percent, but has received a nearly constant level of expenditures in real terms. After a modest initial program, river and flood control received about 30 percent of expenditures over the last three plans, and nearly constant real expenditures over this period.

The completion of physical areas by type of development over the first four Repelitas is shown in Appendix Table 7. Area rehabilitated totaled 950,000 ha in the first plan, and declined steadily thereafter to 150,000 in the latest Repelita. Completions of new irrigated area construction more than doubled between the first and third plans, to 436,000 ha, before declining to 198,000 ha in the fourth plan. Swamp and tidal irrigation peaked at 450,000 ha completed in the third plan, before also declining sharply. Areas brought under river and flood control followed a similar pattern of completions with that of swamp and tidal irrigation.

Appendix Tables 8 and 9 show the planned and actual irrigation development expenditures and planned and actual area completions in Repelita IV. As shown in these tables, the sharp drop in expenditures and area completions between the third and fourth plans was not contemplated when Repelita IV was developed. Planned expenditures in Repelita IV were nearly double those in Repelita III in real terms, and physical targets were equal to or larger than in the third plan across all programs.

The actual Repelita IV program has been cut back dramatically from the original plan by nearly two-thirds compared to planned levels. The cutback has been made fairly evenly across programs, ranging from 57 percent on rehabilitation to 69 percent on new system construction (Appendix Table 8). Physical area completed has declined by a similar order of magnitude compared to planned targets. About 200,000 ha of new irrigation system construction was completed, compared to the original planned area of 600,000 ha. Other programs have experienced cutbacks of similar proportions (Appendix Table 9).

A number of factors have contributed to the reduction in the irrigation investment program in Repelita IV. The government suffered large losses in revenues due to declining oil prices, necessitating major cutbacks in all development programs. The sheer size of the on-going irrigation program caused logistical problems in implementation. Finally, the successes of the rice production program, coupled with declining world rice prices and increasing costs of new irrigation investment, have led to a reassessment of priorities. This reassessment has resulted in increased priority given to efficient operation and maintenance of existing systems, and reduced priority for investment in new irrigation.

3. Philippines

The Philippine analysis is drawn from Azarcon (1990). Trends in rice area harvested, production, and yields from 1966 to 1988 are presented in Appendix Table 10. Aggregate rice production in the Philippines grew at an average rate of 3.2 percent during the full period. Much of this growth was attributable to the increase in production in irrigated production, which had an average growth rate of 5.6 percent per annum from 1966 to 1988. Rice output from non-irrigated areas registered minimal growth over the same period, with actual declines experienced during the period of vigorous irrigation expansion towards the latter half of the 1960s. While production growth under both irrigated and non-irrigated conditions has slowed in the 1980s, the growth in irrigated rice production has continued to outpace that of non-irrigated output.

A conspicuous feature in the trend in rice area harvested is the rapid expansion in irrigated rice hectarage from the late 1960s up to 1972, followed by a period of moderate growth in the mid to late 1970s. Irrigated rice area harvested increased at an average of 7.3 percent per annum from 1966 to 1972, with growth slowing down to around 2.4 percent for the rest of the decade, and declining to 2 percent after 1983.

Physical stock of irrigated hectarage. The National Irrigation Administration (NIA) uses four distinct indicators to refer to the physical stock of areas provided with irrigation service in NIA national systems:

- **project design area** - pre-construction engineering estimate of the maximum area that can be provided with irrigation service, given a project's water supply and infrastructure facilities under ideal conditions.

- **service area** - area where physical irrigation facilities are currently available and water can already be provided.

- **irrigated area** - portion of the service area which actually received irrigation service during the year.

- **benefitted area** - portion of the service area which received enough water to produce a reasonable harvest, i.e., greater than 2 mt/ha per season.

The first indicator is used with reference to projects, while the last three are more commonly used with systems. Project areas become part of the service area of the system in which they are located as soon as sufficient infrastructure facilities have been constructed for the commencement of irrigation service.

Trends in service, and annual irrigated and benefitted rice area in NIA national systems from 1966 to 1985 are compared in Appendix Table 11. Benefitted area in NIA national systems grew at a rate of 5.1 percent, 1970-80, before declining to a growth rate of 2.7 percent in the 1980s. The decline in growth in irrigation area and expenditures can also be seen clearly

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in Appendix Tables 12 and 13. Releases by NIA for capital expenditures for irrigation reached a peak in the late 1970s and early 1980s, but declined dramatically afterward (Appendix Table 12). Average annual expenditures in 1986-87 were only one-fourth as high as in the peak years of 1980-81. New service area generated followed a similar pattern of strong growth, followed by rapid decline, although the peak area generated was reached earlier, in the mid-1970s (Appendix Table 13). By the late 1980s, annual new service areas generated were only about one-fourth of the levels of the mid-1970s.

4. Sri Lanka

This discussion is based on Aluwihare and Kikuchi (1990), who document trends in the irrigation sector in Sri Lanka. Aluwihare and Kikuchi note that rice production can be decomposed into the increases in area planted to rice and rice yield per hectare planted (Appendix Table 14). The annual growth rate of total rice production, 5 percent for 1952-85, was brought about by the increase in area planted at 2 percent per year and an increase in yield per hectare of 3 percent per year. While the growth rate of area planted declined continuously from 3.2 percent in the 1950s to 0.4 percent in the early-1980s, the growth rate of yield per hectare declined from 4 percent in the 1950s to 2.3 percent in the 1970s, but increased to 3.6 percent in the early-1980s, before rapidly declining after the mid-1980s. For all the sub-periods, the contribution of yield increase to the total production was more than that of area increase. It should however be noted that, except for the last sub-period, the two factors maintained nearly the same levels of contribution: 45 percent for the area increase and 55 percent for the yield increase. However, in the last sub-period the contribution of yield increase to the total production growth exceeded 90 percent, as area expansion virtually ceased.

The role played by irrigation development in the growth of rice production can be seen more clearly if the national level annual data are disaggregated into zones and seasons. Appendix Table 15 shows that area planted to rice in major irrigation schemes has continued to increase, but at a declining rate of growth over time. However, area under minor irrigation systems and rainfed area in the dry zone actually decreased for the period of 1980 to 1985. The growth rate in total area irrigated (major and minor) declined from 2.6 percent in 1970-80 to 1.8 percent in 1980-85.

Trends in irrigation investments. Development of the irrigation sector in Sri Lanka has been carried out by the government through massive investments in irrigation infrastructure. Public investments since 1950 are summarized in Appendix Table 16 by type of investment. Irrigation investments are grouped into three categories: new construction, rehabilitation, and operation and maintenance (O&M).

The share of new construction investments in the total irrigation investments was as high as 96 percent in the early 1950s and remained at 80 percent in the late 1980s. Irrigation investments as a whole took nearly 40 percent of the total public investments or nearly 10 percent of the government budget in the 1950s. As the economy developed, the share of the total irrigation investments in the total public investments declined in the mid-1970s. However,

total irrigation investments jumped to an unprecedented high level in and around 1980, increasing the share of irrigation investments in the total public investment to more than 20 percent.

Investments in new construction experienced distinct short- to medium-term fluctuations. Three peaks, or investment spurts, can be discerned: the early-1950s, the late-1960s, and the late-1970s to the early-1980s. During the periods between these peaks, new construction investments decelerated. Major irrigation works found in the first peak are, among others, the Gal Oya, Parakurama Samudra, and Huruluwewa projects, while the second peak consists of such projects as Nagadeepa, Udawalawe, and Rajangana. The third, highest peak was created by the commencement of the Accelerated Mahaweli Development Project in the late 1970s, together with such projects as Inginimitiya and Kirindi Oya. Following completion of these projects, expenditures on new construction have dropped dramatically. Average annual expenditures on new construction in the period centered on 1988 were just over half the annual expenditure during the period centered on 1980.

5. Thailand

Appendix Tables 17 and 18 break down wet and dry season areas and yields by irrigated and non-irrigated area harvested. As shown in Appendix Table 17, the growth rate in area irrigated in the wet season has actually been slightly slower than the growth rate in total wet season area. From 1962/63 to 1974/75, wet season irrigated area grew at a rate of 1.3 percent per year, while total wet season area grew by 1.5 percent per year (all years refer to three-year averages centered on that year). Between 1974/75 and 1982/83, the rate of growth of wet season area irrigated was 2.1 percent, compared to 2.3 percent for total wet season area. As a result, there has been a slight decline in wet season area irrigated as a proportion of total wet season area, from 24.4 percent in 1962/63 to 23.2 percent in 1982/83. Dry season area has virtually doubled since 1975/76, with most of the growth provided by irrigated area (Appendix Table 18). Overall, total area irrigated in both seasons has increased slightly as a percentage of total rice area, from 26.6 percent to 28.6 percent from 1975/76 to 1982/83.

Irrigated yields in the wet season have increased slowly from about 2.5 mt/ha in the early 1960s to over 3.0 mt/ha by 1982/83 (Appendix Table 17). However, unirrigated wet season rice yields have also increased from 1.0 mt/ha in the early 1960s to about 1.4 mt/ha in the early 1980s, so the yield of irrigated wet season rice has not increased relative to non-irrigated rice yields in the wet season.

Since the early 1980's, the dry season crop has contributed more than 2 million mt of rice per year, which is over 10 percent of the total rice output. Therefore, the effect of irrigation has not been only to expand the rice planted area by making dry season cropping possible, but also to increase rice yields in irrigated areas as compared with rainfed areas.

Trends in irrigated area construction and budgets. There are two main types of irrigation projects in Thailand, state irrigation projects, and people's projects. State projects are

primarily medium to large gravity flow projects constructed or contracted out by the RID. People's projects are small projects, such as weirs, canal rehabilitation, drainage structures, pumps, and tanks that require small budgets and relatively simple technology. The government has a policy to provide assistance for the maintenance of people's irrigation projects as well as the construction of new projects which are initiated by the local people, with their contribution in money, labor or materials toward the construction. The construction of small projects which do not require large equipment or high level of technology are the responsibility of the Department of Local Administration in the Ministry of Interior, while larger projects requiring more complex technology are constructed by the RID and then transferred to the Department of Local Administration for maintenance. Virtually all of the people's projects have been undertaken in the northern region of Thailand. Data on people's projects are sparse, but estimates indicate about 350-400,000 ha in these projects in 1983/84.

Area data is much more complete on state irrigation projects. Appendix Table 19 shows the regional breakdown of the government's irrigation development program during 1950-86, defined as state irrigation project areas where construction work has been completed. Table 27 presents the detailed composition of the RID budget by expenditure category.

The irrigation construction area completed, which can be interpreted as a measure of potential irrigated service area, increased from 0.59 million ha in 1950 to 3.82 million ha in 1986 (Appendix Table 19). The growth rate in area completed reached a high of 5.7 percent per year during 1970-80, declining to 4.6 percent per year during the 1980s. In addition, irrigated area completions have increased much more rapidly than effective irrigated rice area harvested. A dramatic decline in effective rice area irrigated as a percentage of completed irrigated service area is indicated, particularly in the wet season. For example, in 1975/76, wet season irrigated rice area was 87 percent of completed irrigated area construction, but by 1982/83 was only 66 percent of completed area. Newly constructed irrigation areas during this period have not been effectively transformed into cropped area.

Investments in new construction have been highly cyclical, as shown in Appendix Table 20. There was a rapid increase in construction expenditures from 1961 to 1970, followed by a sharp decline and then a sustained increase in expenditures through 1985. After this period, investments have again declined significantly.

Appendix Table 1 India: Net irrigated area by sources, 1950-87

Crop Year	Canals Government	Canals Private	Canals Total	Tanks	Wells	Other Sources	TOTAL
			(1,000's Ha)				
1950-51	7,158	1,137	8,295	3,613	5,978	2,967	20,853
1951-52	7,534	1,194	8,728	3,444	6,517	2,360	21,049
1952-53	7,599	1,352	8,951	3,214	6,485	2,427	21,077
1953-54	7,559	1,314	8,873	4,187	6,640	2,087	21,787
1954-55	7,833	1,161	8,994	4,002	6,702	2,261	21,959
1955-56	8,025	1,360	9,385	4,423	6,739	2,211	22,758
1956-57	7,916	1,357	9,273	4,492	6,566	2,202	22,533
1957-58	8,303	1,349	9,652	4,536	6,818	2,150	23,156
1958-59	8,391	1,279	9,670	4,759	6,686	2,286	23,401
1959-60	8,752	1,305	10,057	4,648	7,083	2,208	23,996
1960-61	9,170	1,208	10,378	4,561	7,290	2,440	24,669
1961-62	9,338	1,162	10,500	4,613	7,352	2,420	24,885
1962-63	9,686	1,146	10,832	4,781	7,650	2,403	25,666
1963-64	9,848	1,158	11,006	4,597	7,786	2,484	25,873
1964-65	9,861	1,136	10,997	4,815	7,824	2,520	26,156
1965-66	9,827	1,133	10,960	4,441	8,445	2,595	26,441
1966-67	10,200	1,000	11,200	4,600	9,200	2,200	27,200
1967-68	10,279	1,025	11,304	4,599	9,264	2,356	27,523
1968-69	10,900	1,000	11,900	4,000	10,800	2,400	29,100
1969-70	11,300	1,000	12,300	4,400	11,100	2,500	30,300
1970-71	11,972	866	12,838	4,112	11,887	2,265	31,102
1971-72	11,949	901	12,850	4,140	12,235	2,607	31,832
1972-73	12,192	863	13,055	3,621	13,024	2,249	31,949
1973-74	12,200	900	13,100	3,900	13,300	2,300	32,600
1974-75	12,664	861	13,525	3,548	14,214	2,423	33,710
1975-76	12,933	858	13,791	3,972	14,444	2,386	34,593
1976-77	13,016	845	13,861	3,901	15,087	2,300	35,149
1977-78	13,727	843	14,570	3,899	15,603	2,479	36,551
1978-79	14,283	844	15,127	3,936	16,425	2,569	38,057
1979-80	13,908	842	14,750	3,479	17,860	2,430	38,519
1980-81	14,445	843	15,288	3,196	17,775	2,582	38,841
1981-82	14,681	844	15,525	3,506	18,167	2,566	39,764
1982-83	14,875	495	15,370	3,112	19,112	2,375	39,969
1983-84	15,745	495	16,240	3,783	19,521	2,411	41,955
1984-85	15,366	495	15,861	3,330	19,988	2,600	41,779
1985-86	15,604	487	16,091	3,157	20,517	2,650	42,414
1986-87	15,841	479	16,320	2,983	21,046	2,700	43,049

Sources: Svendsen, from, for 1950/51 - 1977/78: (1) The Ford Foundation, Data on the Indian Economy 1951-1969. (New Delhi: Ford Foundation 1970); (2) Department of Agriculture, Indian Agriculture in Brief. 21st Edition. (New Delhi, 1987); (3) Ministry of Irrigation and Power, Report of the Irrigation Commission. (New Delhi, 1972); (4) Central Statistical Organization, Statistical Pocket Book of India. (New Delhi: Department of Statistics, Ministry of Planning, 1980).

For 1978/79 - 1984/85: Ministry of Agriculture, Indian Agriculture in Brief, 22nd Edition. (New Delhi, 1988). Data for 1982/83 - 1984/85 is provisional.
For 1985/86: values are simple linear interpolations of surrounding years.
For 1986/87: Fertilizer Association of India, Fertilizer Statistics 1989-90. (New Delhi, 1991).

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Appendix Table 2 **India: Annual Growth Rates[a], All-India Net Irrigated Area by Source**

Period	Canals[b]	Tanks	Tube-Wells[c]	Dug-Wells[c]	Total Wells	Other Sources	Net Irrigated Area
				(percent)			
1950-60	1.95	3.44	-	-	1.23	-0.13	1.68
1960-70	1.92	-1.14	-	-	5.52	-0.43	2.33
1970-80	1.95	-1.41	7.92	1.44	4.33	0.78	2.47
1980-86	1.07	-1.21	4.14	1.29	2.87	1.05	1.73
1950-86	1.86	-0.25	-	-	3.43	0.16	2.08

[a] Growth rates are based on linear trends fitted to each time period.

[b] Includes both government and private canals.

[c] Prior to 1970, tubewell and dugwell areas not available individually.

Source: Computed from data in Appendix Table 1.

Appendix Table 3 **India: Capital cost expenditures on irrigation development (major and medium schemes)**

Plan Period	Expenditure (Rs Crores) Current Prices Total	at 1970/71 prices Total	Annual Average
First Plan (1951-56)	380	827	165.4
Second Plan (1956-61)	380	706	141.2
Third Plan (1961-66)	581	883	176.6
Annual Plan (1966-69)	434	526	175.3
Fourth Plan (1969-74)	1,237	1,124	224.8
Fifth Plan (1974-78)	2,442	1,392	348.0
Annual Plans (1978-80)	2,056	867	433.5
Sixth Plan (1980-85)	7,369	1,969	393.8
Seventh Plan (1985-90) (anticipated)	11,343	1,682	336.4

Source: Gulati, from Government of India (1989): Report of the Working Group on Major and Medium Irrigation Process for the Eighth Plan (1990-95).

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Appendix Table 4 Indonesia: Irrigated and Wetland Area, Dryland Area, and Total Area, Yield, and Production of Paddy in 1969-87

Year	Irrigated & Wetland Area			Dryland Area			Area			Yield			Production		
	Java	Off-Java	Total	Java	Off-Java	Total	Java	Off-Java	Total	Java	Off-Java	Total	Java	Off-Java	Total
	------ '000 ha --------			------ '000 ha ------			------ '000 ha --------			-------- mt/ha --------			------- '000 mt ---------		
1969	3933	2611	6544	345	1124	1469	4278	3735	8014	2.57	1.88	2.25	11003	7010	18013
1970	3947	2732	6679	341	1115	1456	4288	3847	8135	2.70	2.01	2.38	11580	7744	19324
1971	4037	2856	6893	365	1066	1431	4402	3922	8324	2.81	1.99	2.42	12389	7793	20182
1972	3992	2610	6602	326	970	1296	4318	3580	7898	2.76	2.09	2.45	11896	7490	19386
1973	4226	2838	7064	331	1009	1340	4557	3847	8404	2.86	2.20	2.56	13016	8465	21481
1974	4434	2906	7340	285	884	1169	4719	3790	8509	2.94	2.27	2.64	13853	8611	22464
1975	4379	2955	7334	265	896	1161	4644	3851	8495	2.95	2.24	2.63	13701	8630	22331
1976	4203	3026	7229	249	890	1139	4452	3916	8369	3.15	2.37	2.78	14031	9270	23301
1977	4115	3087	7202	245	913	1158	4360	4000	8360	3.00	2.57	2.79	13080	10267	23347
1978	4447	3251	7698	284	947	1231	4731	4198	8929	3.29	2.43	2.89	15551	10221	25772
1979	4393	3282	7675	217	912	1129	4610	4194	8804	3.40	2.53	2.99	15655	10627	26283
1980	4503	3316	7824	253	933	1186	4756	4249	9005	3.86	2.66	3.29	18358	11294	29652
1981	4763	3428	8191	266	924	1190	5029	4352	9382	4.07	2.83	3.49	20478	12296	32774
1982	4488	3385	7873	247	868	1115	4735	4253	8988	4.39	3.00	3.74	20806	12778	33584
1983	4479	3508	7987	291	885	1176	4770	4393	9162	4.53	3.12	3.85	21595	13707	35303
1984	4852	3695	8547	350	867	1217	5202	4562	9764	4.55	3.17	3.91	23666	14471	38136
1985	4965	3704	8669	307	855	1162	5272	4559	9832	4.59	3.25	3.97	24217	14808	39025
1986	4986	3827	8813	345	831	1176	5331	4658	9989	4.59	3.50	4.08	24459	16297	40756
1987	4971	3866	8837	214	871	1085	5185	4737	9922	4.73	3.24	4.04	24544	15535	40079

Source: Rosegrant and Pasandaran, from Central Bureau of Statistics.

Appendix Table 5 Indonesia: Potential irrigated service area in Public Works Systems, by type of system, 1969-87

Year	Total Irrigated Service Area			Technical Irrigated Service Area			Semi-Technical Irrigated Service Area			Simple Irrigated Service Area		
	Java	Off-Java	Indo.	Java	Off-Java	Indo.	Java	Off-Java	Indo.	Java	Off-Java	Indo.
	'000 ha											
1969	2,506	882	3,388	1,172	298	1,470	973	301	1,274	361	283	64
1970	2,513	923	3,436	1,240	309	1,549	918	330	1,248	355	284	63
1971	2,506	982	3,488	1,291	281	1,572	664	342	1,003	554	359	91
1972	2,513	1,004	3,517	1,380	295	1,675	583	352	935	550	357	90
1973	2,518	1,028	3,546	1,446	309	1,755	524	359	883	548	360	90
1974	2,522	1,135	3,657	1,518	233	1,751	430	447	877	574	455	1,02
1975	2,521	1,236	3,757	1,522	269	1,786	431	504	935	568	468	1,03
1976	2,555	1,289	3,844	1,557	313	1,870	467	473	940	531	503	1,03
1977	2,557	1,385	3,942	1,563	318	1,881	435	516	951	559	551	1,11
1978	2,581	1,437	4,018	1,575	340	1,915	459	530	989	547	567	1,11
1979	2,592	1,470	4,063	1,604	357	1,961	441	587	1,028	548	526	1,07
1980	2,608	1,500	4,107	1,642	365	2,007	427	639	1,066	539	496	1,03
1981	2,623	1,529	4,152	1,680	373	2,053	414	690	1,104	529	466	99
1982	2,637	1,558	4,195	1,717	381	2,099	401	741	1,142	519	436	95
1983	2,656	1,586	4,241	1,752	393	2,145	390	790	1,180	514	403	91
1984	2,735	1,670	4,405	1,807	424	2,231	338	811	1,149	590	435	1,02
1985	2,696	1,717	4,413	1,808	429	2,237	363	839	1,202	525	449	974
1986	2,698	1,924	4,622	1,861	544	2,405	305	864	1,169	532	516	1,048
1987	2,970	2,388	5,358	2,069	691	2,760	314	1,032	1,346	587	665	1,252

Source: Ministry of Public Works, DGWRD.

Appendix Table 6 **Indonesia: Total Irrigation Development Expenditure by Type of Development, Repelita I through Repelita IV**

Five-Year Development Plan/ Type of Development	Current Cost Rp billion	Real Cost[b] Rp billion	% Distribution
Repelita I (1969-73)	114.4	171.9	100.0
Rehabilitation	50.0	73.7	42.3
New construction	25.0	38.3	22.3
Swamp/tidal	33.1	50.0	29.1
River and flood control	6.4	9.9	5.7
Repelita II (1974-78)	617.1	582.3	100.0
Rehabilitation	147.6	138.8	23.8
New construction	197.3	185.7	31.9
Swamp/tidal	152.3	50.1	8.6
River and flood control	219.9	207.8	35.7
Repelita III (1979-83)	1,908.2	913.1	100.0
Rehabilitation	556.3	263.4	28.8
New construction	759.8	358.0	39.2
Swamp/tidal	109.7	54.6	6.0
River and flood control	482.4	237.2	26.0
Repelita IV (1984-88)[a]	2,294.6	748.2	100.0
Rehabilitation	550.5	179.5	24.0
New Construction	967.6	315.5	42.2
Swamp/tidal	115.2	37.6	5.0
River and flood control	661.3	215.6	28.8

[a] Actual expenditure, 1984/85-1986/87; preliminary estimated expenditure, 1987/88- 1988/89.

[b] Constant 1975/76 rupiah.

Source: Ministry of Public Works, DGWRD.

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Appendix Table 7 **Indonesia: Physical Area Completed, by Type of Development, Repelita I through Repelita IV**

Type of Development	Repelita I 1969-73	Repelita II 1974-78	Repelita III 1979-83	Repelita IV 1984-88
	'000 ha			
Rehabilitation	953.5	527.8	394.7	151.7
New construction	191.2	325.9	436.2	197.9
Swamp/tidal	178.7	179.2	454.5	120.3
River and flood control	289.4	613.7	578.5	256.0

Source: Ministry of Public Works, DGWRD.

Appendix Table 8 **Indonesia: Irrigation Development Expenditures by Type of Development, planned and actual, Repelita IV**

Type of Development	Plan 1984/85-1988/89	Actual 1984/85	1985/86	1986/87	1987/88	1988/89	Total
	Rp billion						
Rehabilitation	1,265.0	177.3	149.2	70.9	83.7	69.4	550.5
New construction	3,131.4	141.2	240.3	190.7	234.4	161.0	967.6
Swamp/tidal	271.5	34.8	27.5	16.4	23.7	12.8	115.2
River and flood control	1,665.6	163.6	145.2	94.2	163.2	95.1	661.3
Total	6,333.5	516.9	562.2	372.2	505.0	338.3	2,294.6

Source: Ministry of Public Works, DGWRD.

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Appendix Table 9 **Indonesia: Physical Area Planned, Completed and Projected, by type of development, Repelita IV**

Type of Development	Plan 1984/85-1988/89	Completed[a] 1984/85	1985/86	1986/87	1987/88	1988/89	Total
	'000 ha						
Rehabilitation	360.0	43.6	29.0	24.7	34.4	20.0	151.7
New construction	600.0	48.0	44.1	43.7	40.1	22.0	197.9
Swamp/tidal	460.0	60.5	33.9	4.8	16.6	5.0	120.3
River and flood control	500.0	62.2	54.5	34.1	72.2	34.0	256.0

[a] Actual completions, 1984/85-1986/87. Preliminary estimated completions, 1987//88-1988/89

Source: Ministry of Public Works, DGWRD.

Appendix Table 10 Philippines: Rice Production, Area, and Yield, 1966-88

	1966-88	1966-72	1973-78	1979-82	1983-88
Average Annual Growth Rate(%):					
Production	3.2	2.5	5.8	3.1	1.3
Irrigated	5.6	6.4	7.5	5.2	3.2
Non-irrigated	0.3	-3.2	4.0	0.2	0.2
Area Harvested	0.3	1.2	1.4	-1.1	-0.7
Irrigated	3.6	7.3	2.5	2.4	2.0
Non-irrigated	-2.7	-4.5	0.8	-3.9	-3.5
Yield per Hectare	2.8	1.4	4.1	4.2	2.0
Irrigated	2.2	0.3	4.6	2.8	1.1
Non-irrigated	2.9	2.8	3.1	4.3	1.7
Average Yield (metric tons per hectare):					
Irrigated	2.5	1.9	2.3	2.9	3.1
Non-irrigated	1.5	1.2	1.3	1.7	1.9

Source of basic data: Azarcon, from Bureau of Agricultural Statistics.

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Appendix Table 11 **Philippines: NIA Service and Benefitted Areas, 1967-85, national systems, wet and dry seasons (in thousand hectares)**

Year	Service Area	Wet Season Benefitted Area	Wet Season % Service Area	Dry Season Benefitted Area	Dry Season % Service Area	Dry Season % Wet Season Benefitted Area
1967	298.0	242.0	81.2	88.0	29.5	36.3
1968	319.0	246.8	77.4	101.8	31.9	41.3
1969	357.5	259.3	72.5	102.8	28.8	39.7
1970	395.9	283.4	71.6	102.0	25.8	36.0
1971	398.7	288.5	72.4	124.3	31.2	43.1
1972	404.9	269.8	66.6	133.4	32.9	49.4
1974	355.0	317.6	89.5	156.0	43.9	49.1
1975	396.3	317.9	80.2	173.0	43.7	54.4
1976	335.9	336.8	77.3	212.4	48.7	63.1
1977	455.9	359.3	78.8	194.0	42.6	54.0
1978	463.7	344.5	74.3	262.0	56.5	76.1
1979	475.2	352.5	74.2	269.5	56.7	76.5
1980	492.2	353.6	74.9	279.9	59.3	79.1
1981	491.7	356.8	72.6	278.9	56.7	78.2
1982	514.3	376.5	73.2	305.0	59.3	81.0
1983	550.0	342.3	62.2	270.1	49.1	78.9
1984	548.3	383.8	70.0	263.2	48.0	68.6
1985	568.2	397.9	70.0	328.0	57.7	82.4

Source of basic data: Azarcon, from National Irrigation Administration.

Appendix Table 12 **Philippines: NIA Releases for Capital Expenditure, 1966-87 (in million pesos)**

Constant 1982 Prices				Current Terms				At
Year	National Total	Communal	Pump/ Private	Total	National	Communal	Private	
Pump/								
1966	0.93	0.49	1.54	2.96	6.23	3.30	10.36	19.89
1967	9.48	0.93	5.70	16.11	59.24	5.81	35.63	100.68
1968	23.22	1.03	11.63	35.89	136.35	6.08	68.32	210.75
1969	23.47	1.19	8.64	33.31	133.05	6.77	49.01	188.84
1970	23.66	1.29	9.47	34.42	115.46	6.30	46.24	168.00
1971	61.53	1.70	17.74	80.97	271.04	7.51	78.15	356.70
1972	119.88	2.99	15.59	138.45	492.12	12.27	63.98	568.37
1973	238.20	6.29	15.00	259.49	827.37	21.85	52.10	901.32
1974	568.12	14.71	23.19	606.02	1232.09	31.91	50.29	1314.29
1975	819.17	32.41	24.89	876.48	1766.22	69.89	53.67	1889.77
1976	832.09	44.28	22.26	898.63	1662.19	88.45	44.47	1795.11
1977	899.44	59.14	13.91	972.49	1666.25	109.56	25.77	1801.57
1978	1088.20	16.06	11.77	1116.03	1851.31	27.32	20.02	1898.66
1979	1360.24	29.80	3.76	1393.80	1931.34	42.31	5.34	1978.79
1980	2251.92	151.13	0.44	2403.49	2751.95	184.69	0.54	2937.17
1981	1968.32	177.84	-	2146.16	2116.25	191.21	0.00	2307.45
1982	1881.46	165.27	-	2046.73	1881.46	165.27	0.00	2046.73
1983	1584.83	195.85	-	1780.68	1440.91	178.07	0.00	1618.98
1984	1074.53	254.83	-	1329.36	654.83	155.30	0.00	810.13
1985	1484.06	221.16	-	1705.22	763.13	113.72	0.00	876.85
1986	834.2	193.23	-	1027.45	407.77	73.83	0.00	554.23
1987	971.06	451.33	-	1422.39	444.83	169.51	0.00	769.97

Source: Azarcon, from National Irrigation Administration.

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Appendix Table 13 **Philippines: Generated Service Area, 1965-87 (in hectares)**

Year	National	Communal	Pump/Private	Total
1966	0	3,996	2,900	6,896
1967	0	8,105	2,911	11,016
1968	6,908	7,545	2,183	16,636
1969	26,391	53,810	1,637	82,338
1970	13,862	8,614	1,228	23,704
1971	22,787	3,015	3,685	29,487
1972	20,376	10,524	6,696	37,598
1973	18,535	11,587	2,678	32,800
1974	23,489	29,833	20,086	73,408
1975	19,262	53,805	20,253	93,320
1976	18,030	42,382	9,579	69,991
1977	20,232	39,293	9,579	69,104
1978	17,316	16,623	9,803	45,747
1979	15,763	23,568	3,041	43,170
1980	20,147	27,659	457	48,263
1981	24,918	22,330	0	47,248
1982	28,451	32,021	0	60,472
1983	34,601	14,735	0	49,336
1984	20,008	9,970	0	29,978
1985	21,651	6,292	0	27,943
1986	20,913	3,729	0	24,642
1987	14,963	4,291	0	19,274
1988	14,428	11,520	0	25,948

Source: Azarcon, from National Irrigation Administration.

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Appendix Table 14 **Sri Lanka: Annual Compound Growth Rates of Rice Production, area planted, and yield per hectare**

	Annual compound growth rates (%)		
	Rice production	Area planted	Yield per ha
1952-1960	7.2 (100)	3.2 (44)	4.0 (56)
1960-1970	5.0 (100)	2.2 (44)	2.8 (56)
1970-1980	3.9 (100)	1.6 (41)	2.3 (59)
1980-1985	4.0 (100)	0.4 (10)	3.6 (90)
1951-1985	5.0 (100)	2.0 (40)	3.0 (60)

Source: Appendix Table A-2 in Aluwihare and Kikuchi, 1990.

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Appendix Table 15 Sri Lanka: Total Area Planted to Rice, by zone and by type of irrigation, 1952-85

	Total	Dry Zone						Wet Zone
		Major irrigation			Minor irrigation	Rainfed	Total	
		Maha	Yala	Total				
1952	458.2	47.9	46.8	94.6	54.3	71.1	220.0	238.3
	(100)	(11)	(10)	(21)	(12)	(16)	(48)	(52)
1960	584.5	86.3	66.8	153.1	84.6	102.7	340.1	244.1
	(100)	(15)	(11)	(26)	(15)	(18)	(58)	(42)
1970	727.8	132.7	82.7	215.4	103.0	125.7	444.1	283.6
	(100)	(18)	(11)	(30)	(14)	(17)	(61)	(39)
1980	857.7	188.7	107.5	295.7	114.3	154.1	564.1	293.7
	(100)	(22)	(13)	(35)	(13)	(18)	(66)	(34)
1985	874.4	207.0	136.9	343.8	102.6	123.0	569.5	304.9
	(100)	(24)	(16)	(39)	(12)	(14)	(65)	(35)
Growth rate (%):								
1952-60	3.2	7.6	4.5	6.2	5.7	4.7	5.6	0.3
1960-70	2.2	4.4	2.2	3.5	2.0	2.0	2.7	1.5
1970-80	1.6	3.6	2.7	3.2	1.0	2.1	2.4	0.4
1980-85	0.4	1.9	5.0	3.1	-2.1	-4.4	0.2	0.8
1952-85	2.0	4.5	3.3	4.0	1.9	1.7	2.9	0.7

Note: Five-year averages centering the years shown. Figures in parenthesis are percentage.

Source: Appendix Table A-4 in Aluwihare and Kikuchi, 1990.

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Appendix Table 16 Sri Lanka: Irrigation Investments, by type of investment, in 1986 constant prices, and their share in the government budget and the total public investments, 1950 to 1988[a]

	Irrigation Investments				Share of the total irrigation investments[e] in	
	New construction	Rehabilitation[c]	Operation & maintenance	Total	Government budget	Total public investment
	Rs million in 1986 prices				%	
1950	907 (96)	-	34 (4)	941 (100)	8	37
1955	859 (96)	-	38 (4)	897 (100)	6	29
1960	601 (83)	-	121 (17)	723 (100)	3	19
1965	619 (91)	-	62 (9)	681 (100)	3	15
1970	994 (93)	-	78 (7)	1071 (100)	3	16
1975	1116 (89)	5 (1)	127 (10)	1248 (100)	2	13
1980	3023 (89)	225 (7)	137 (4)	3385 (100)	6	21
1985	2770 (82)	451 (13)	141 (4)	3362 (100)	6	18
1988	1676 (81)	299 (15)	89 (4)	2064 (100)	3	na

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

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

[c] Investment for major rehabilitation and modernizing existing systems.

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

[e] Ratios are obtained between the series in current prices.

Sources: Appendix Tables A-7 and A-8 in Aluwihare and Kikuchi, 1990.

Appendix Table 17 Thailand: Comparison of Rice Areas and Yields in Irrigated and Unirrigated Areas and the Whole Kingdom, wet season, 1958/59-1983/84

Crop Year	Wet Season Area				Wet Season Yield			
	Irrig. Project Area	Outside Project Area	Whole Kingdom	Ratio of Proj. area to Whole Kingdom (%)	Irrig. Project Area	Outside Project Area	Whole Kingdom	Ratio of Production in Project Area to Whole Kingdom (%)
	'000 ha				mt/ha			
1958/59	1,363	4,395	5,758	23.67	2.23	0.90	1.21	43.5
1959/60	1,318	4,747	6,066	21.74	2.16	0.81	1.10	42.5
1960/61	1,370	4,552	5,922	23.13	2.57	0.93	1.31	45.4
1961/62	1,428	4,741	6,168	23.14	2.54	0.94	1.31	45.2
1962/63	1,629	5,019	6,648	24.50	2.54	1.02	1.39	44.7
1963/64	1,678	4,923	6,602	25.42	2.58	1.58	1.52	43.2
1964/65	1,762	4,778	6,539	26.94	2.29	1.16	1.46	42.2
1965/66	1,754	4,800	6,554	26.76	2.48	1.01	1.40	47.3
1966/67	1,768	5,664	7,432	23.79	2.52	1.32	1.61	37.3
1967/68	1,763	4,894	6,658	26.48	2.60	1.03	1.45	47.6
1968/69	1,768	5,459	7,227	24.46	2.52	1.08	1.43	43.1
1969/70	1,802	5,835	7,637	23.59	2.39	1.55	1.75	32.3
1970/71	1,838	5,963	7,802	23.56	2.42	1.50	1.72	33.2
1971/72	1,872	6,131	8,003	23.39	2.68	1.50	1.77	35.3
1972/73	1,808	5,331	7,139	25.32	2.55	1.32	1.63	39.5
1973/74	1,822	5,789	7,611	23.94	2.75	1.54	1.83	36.0
1974/75	1,856	5,472	7,328	25.33	2.51	1.45	1.72	37.0
1975/76	1,882	6,530	8,411	22.37	2.52	1.69	1.87	30.1
1976/77	1,914	6,526	8,440	22.67	2.78	1.72	1.96	32.2
1977/78	1,941	6,458	8,398	23.11	2.82	1.05	1.46	44.7
1978/79	2,035	7,242	9,277	21.94	2.76	1.41	1.71	35.5
1979/80	2,056	7,166	9,222	22.29	2.87	1.32	1.67	38.3
1980/81	2,061	7,742	9,803	21.02	2.97	1.42	1.75	35.7
1981/82	2,123	7,402	9,525	22.29	2.95	1.41	1.75	37.5
1982/83	2,192	7,021	9,213	23.79	3.06	1.28	1.70	42.8
1983/84	2,250	7,260	9,510	23.66	2.95	1.42	1.81	44.7

Source: Rosegrant and Mongkolsmai, from Royal Irrigation Department.

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Appendix Table 18 **Thailand: Comparison of Rice and Yield in Irrigated Areas and the Whole Kingdom, dry season, 1975-85**

Crop Year	Dry Season Area				Dry Season Yield		
	Irrig. Project Area	Outside Project Area	Whole Kingdom	Ratio of Proj. Area to Whole Kingdom	Irrig. Proj. Area	Outside Proj. Area	Whole Kingdom
	'000 ha				mt/ha		
1974/75	306	25	331	94.45	2.96	1.30	2.84
1975/76	370	7	377	98.14	3.23	1.65	3.20
1976/77	408	30	438	93.15	3.28	1.82	3.18
1977/78	407	70	477	85.32	3.60	1.74	3.33
1978/79	565	116	681	82.97	3.59	2.03	3.32
1979/80	260	76	336	77.38	3.87	1.38	3.30
1980/81	516	0	516	100.00	3.80	-	3.80
1981/82	572	0	572	100.00	3.52	-	3.52
1982/83	607	27	634	95.71	3.39	1.61	3.27
1983/84	607	110	717	84.68	3.99	1.67	3.63
1984/85	569	137	706	80.57	3.92	2.92	3.72

Source: Rosegrant and Mongkolsmai, from Royal Irrigation Department.

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Appendix Table 19 Thailand: State irrigation project areas where construction has been completed, Thailand, 1950-86

Year	REGION									
	North		Northeast		Central		South		Whole Kingdom	
	'000 ha	%	'000 ha	%	'000 ha	%	'000 ha	%	'000 ha	%
1950	42.88	7.22	0.96	0.16	545.44	91.89	4.32	0.73	593.60	100
1951	43.52	7.29	4.00	0.67	545.44	91.32	4.32	0.72	597.28	100
1952	47.20	7.75	8.00	1.31	546.88	89.80	6.88	1.13	608.96	100
1953	55.84	8.54	13.44	2.05	576.32	88.11	8.48	1.30	654.08	100
1954	57.76	8.43	14.88	2.17	596.96	87.09	15.84	2.31	658.44	100
1955	89.92	10.00	59.04	6.57	720.32	80.12	29.76	3.31	899.04	100
1956	90.88	9.64	79.68	8.45	742.72	78.76	29.76	3.15	943.04	100
1957	90.88	9.45	96.32	10.02	744.00	77.40	30.08	3.13	961.28	100
1958	90.88	9.20	123.20	12.47	744.00	75.29	30.08	3.04	988.16	100
1959	92.80	9.27	133.60	13.35	744.00	74.36	30.08	3.01	1,000.48	100
1960	92.80	9.14	134.08	13.20	758.40	74.69	30.08	2.96	1,015.36	100
1961	92.80	9.06	142.56	13.92	758.40	74.07	30.08	2.94	1,023.84	100
1962	103.68	9.57	144.00	13.29	792.16	73.14	43.20	3.99	1,083.04	100
1963	135.04	9.52	151.52	10.68	1,088.48	76.75	43.20	3.05	1,418.24	100
1964	135.04	8.86	155.20	10.18	1,191.04	78.13	43.20	2.83	1,524.48	100
1965	135.04	8.75	156.64	10.14	1,209.12	78.31	43.20	2.80	1,544.00	100
1966	137.44	8.88	158.72	10.25	1,205.92	77.88	46.40	3.00	1,548.48	100
1967	145.92	9.37	158.72	10.19	1,205.92	77.45	46.40	2.98	1,556.96	100
1968	145.92	9.34	161.28	10.32	1,205.92	77.19	49.12	3.14	1,562.24	100
1969	241.44	14.87	165.28	10.18	1,168.32	71.93	49.12	3.02	1,624.16	100
1970	241.44	14.43	174.40	10.42	1,206.72	72.12	50.72	3.03	1,673.28	100
1971	266.72	15.66	174.40	10.24	1,207.52	70.90	54.40	3.19	1,703.04	100
1972	290.40	16.14	174.72	9.71	1,279.84	71.13	54.40	3.02	1,799.36	100
1973	300.80	15.72	178.40	9.32	1,378.40	72.05	55.52	2.90	1,913.12	100
1974	360.80	17.78	190.08	9.37	1,381.92	68.09	96.64	4.76	2,029.44	100
1975	363.52	17.51	191.04	9.20	1,424.32	68.62	96.64	4.66	2,075.52	100
1976	391.04	16.23	224.96	9.34	1,627.68	67.58	164.96	6.85	2,408.64	100
1977	452.48	17.91	245.28	9.71	1,646.88	65.18	182.08	7.21	2,526.72	100
1978	491.36	18.40	277.44	10.39	1,672.96	62.65	228.48	8.56	2,670.24	100
1979	582.64	18.87	308.48	11.01	1,722.56	61.50	241.12	8.61	2,800.80	100
1980	574.72	19.71	340.80	11.69	1,743.52	59.81	256.16	8.79	2,915.20	100
1981	601.44	20.11	359.68	12.02	1,878.72	59.46	251.52	8.41	2,991.36	100
1982	660.16	20.87	406.40	12.85	1,827.04	57.75	269.92	8.53	3,171.52	100
1983	746.08	22.47	438.56	13.21	1,844.96	55.56	290.88	8.76	3,320.48	100
1984	817.76	23.60	473.44	13.66	1,855.04	53.54	318.88	9.20	3,464.96	100
1985	870.88	23.80	522.40	14.28	1,929.60	52.74	335.52	9.17	3,658.40	100
1986	934.56	24.45	579.04	15.15	1,947.68	60.96	360.96	9.44	3,822.24	100

Source: Rosegrant and Mongkolsmai, from Royal Irrigation Department.

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Appendix Table 20 Thailand: Royal Irrigation Department real annual budget at 1976 prices, Thailand, 1961-87

Year	Total Budget	General	Operation & Maintenance	Construction		
				State Projects	People's Projects	Total Construction
	million Baht					
1961	754.33	87.70	104.44	491.33	70.86	562.19
1962	1,028.89	133.10	141.52	637.06	117.21	754.27
1963	1,241.82	128.14	183.14	791.60	138.94	930.54
1964	1,095.53	149.56	229.93	629.98	86.06	716.04
1965	1,552.61	386.05	288.08	742.03	136 45	878.48
1966	1,654.48	311.89	290.88	900.74	150.97	1,051.71
1967	2,173.96	314.55	376.09	1,282.58	200.75	1,483.33
1968	2,636.53	324.80	457.25	1,489.11	365.37	1,854.48
1969	2,950.28	392.65	504.50	1,595.42	457.72	2,053.14
1970	3,832.84	926.07	626.73	1,539.48	740.54	2,280.02
1971	3,631.75	1,162.47	349.47	1,411.10	708.71	2,119.81
1972	2,978.77	1,007.83	330.22	1,069.39	571.35	1,640.74
1973	1,935.04	794.29	258.60	546.25	335.90	882.15
1974	1,825.04	708.09	219.57	602.77	295.50	898.27
1975	2,587.53	884.70	350.06	911.75	441.03	1,352.78
1976	3,161.24	1,096.73	537.39	936.43	590.70	1,527.13
1977	3,137.19	1,093.79	549.05	843.51	650.84	1,494.35
1978	3,329.45	967.06	657.85	1,042.13	662.41	1,704.54
1979	3,456.06	1,014.23	975.85	1,169.88	296.09	1,465.97
1980	3,448.55	935.90	912.33	1,151.47	448.86	1,600.33
1981	4,269.63	1,096.19	1,156.45	1,360.90	656.09	2,016.99
1982	4,729.26	713.35	1,716.43	1,618.43	681.05	2,299.48
1983	4,916.14	1,258.17	1,259.17	1,684.06	714.73	2,398.79
1984	5,221.08	1,355.19	1,362.27	1,666.64	836.98	2,503.62
1985	5,398.72	1,451.98	1,435.49	1,662.12	849.14	2,511.26
1986	5,090.45	1,478.09	1,343.69	1,623.73	644.94	2,268.67
1987	4,793.21	1,509.91	1,377.23	1,222.04	684.02	1,906.26

Source: Rosegrant and Mongkolsmai, from Royal Irrigation Department.