Irrigation Design and Management
Experience in Thailand and Its General Applicability

Herve L. Plusquellec and Thomas Wickham
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ABSTRACT

The degree of performance achieved in managing irrigation projects depends on a number of physical, social and institutional factors and to a large extent on the basic physical infrastructure provided. The first four chapters of this paper examine how these various factors affect the irrigation system performance in one country - Thailand - which has a long history of irrigation. The paper first briefly describes the physical characteristics of Thailand which affect irrigated agriculture, then gives an overview of Thailand's irrigation development and the objectives which have determined system design, and finally analyzes the various factors now constraining system performance throughout the country.

The concluding chapters explore the general topics of main system improvement and tertiary system development, and are implicitly aimed at the controversial question of whether irrigation performance can be improved solely through improved management or whether physical facilities need to be upgraded as well. This section of the report reviews the main approaches now available to improve canal system management in new and rehabilitated projects. It indicates that each approach has different managerial and financial requirements and should not be used indiscriminately. The paper goes on to examine the impact of design and management on water distribution at the farm level and the relation of the tertiary system to the main system. In general, the paper finds that management alone may not substantially improve irrigation performance but, if combined with physical improvements at a modest cost, it may have a major impact on performance.

The paper would be of interest to irrigation project planners, designers and managers since the lessons learned from the Thai experience are applicable to many countries, particularly those in the humid tropics. The paper also provides a general review of the technological and other options available to improve irrigation system performance and thus has widespread applicability.
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MAPS
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FOREWORD

1. This report was initiated as a supporting document to a comprehensive irrigation subsector review to be completed in 1985. As such, it focuses only on those aspects of Thai irrigation which are relevant to water management. While the findings of the report have obvious implications for other aspects of irrigation development such as engineering standards and RID's organization, policies, and institutional development, these elements are referred to only in relation to water management, the issue immediately at hand. Although a case study of Thailand, it is believed that the concepts and analysis provided in the report are also relevant to many other countries, particularly those in the humid tropics.

2. Development of the irrigation system in Thailand is now at a critical point. The existing system was for the most part constructed to service wet season rice over an extensive area but providing only limited control over irrigation water. Now, although wet season rice remains the dominant crop, the increasing importance of dry season rice and the desirability of diversified cropping in some areas have created a need for improved water management able to provide irrigation water where, when, and in the amount needed. The Government of Thailand, through its Royal Irrigation Department (RID), intends to expand its past efforts to improve water management, which concentrated on the tertiary or on-farm system, and is planning a comprehensive system-wide program responsive to the country's changing irrigation requirements. It is hoped that this report will assist RID in its planning by discussing the various constraints that need to be overcome and the range of objectives, concepts and technologies which have a bearing on any final decision on how to proceed. The report is deliberately exploratory and suggestive rather than prescriptive since the management problems of an irrigation system as large and as varied as that in Thailand cannot be generalized and are not open to easy solutions. Each system presents its own set of conditions and its own specific challenge.

3. The paper is based on the findings of several reports on water use in Thai irrigation projects and on observations gathered during field visits. As such, it does not pretend to be technically comprehensive and may include some incorrect interpretations of facts and of constraints presented by local conditions. Discussions of both the main and tertiary systems are included since experience in other countries has indicated that emphasis on one aspect of irrigation, rather than consideration of the system as a whole, has often led to unsatisfactory results.

4. Chapter 1 of the report briefly describes the physical characteristics of Thailand that affect irrigation potential and agriculture, i.e., river basin area, climate and soils. It goes on to describe the country's cropping pattern and the dominance of wet season rice. Chapter 2 gives an overview of irrigation development in Thailand and the objectives which have heretofore determined irrigation system design. Thereafter, the factors generally constraining irrigation performance at all levels and in almost all systems are discussed. These include the physical problem posed by the country's uneven pattern of rainfall as well as the constraints caused by design and maintenance problems. Chapter 4 indicates how the various problems are manifested
in typical systems nationwide. How to correct these problems is the subject of the latter part of the report which provides a more general discussion of techniques to improve performance of the main and tertiary systems and the limits and applicability of these methods.
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WEIGHTS AND MEASURES

1 meter (m) = 3.28 feet
1 millimeter (mm) = 0.039 inch
1 kilometer (km) = 0.62 miles
1 hectare (ha) = 2.47 acres = 6.25 rai
1 million cubic meters (mcm) = 810 acre-feet
1 ton = 1,000 kilograms (kg) = 2,205 pounds
1 cubic meter per second (cu m/sec) = 35.3 cubic feet per second
1 square kilometer (sq km) = 0.39 square mile

ABBREVIATIONS

CHO - Constant head orifice
EGAT - Electricity Generating Authority of Thailand
ET - Evapotranspiration
FTO - Farm turnout
HYV - High-yielding variety
IRRI - International Rice Research Institute, Los Banos, Philippines
MOAC - Ministry of Agriculture and Cooperatives
NESDB - National Economic and Social Development Board
O&M - Operation and maintenance
RID - Royal Irrigation Department
S&P - Seepage and Percolation
WOC - Water operation center
WMS - Water management system
SUMMARY AND RECOMMENDATIONS

Background. The conservation and development of water resources have always been central issues in the social, economic and political realities of arid and semi-arid countries. They have now become of vital interest to countries in the humid tropical regions as well. This is true for Thailand where the concept of water as a free resource to be used and even squandered at will did not pose serious problems until the early 1970s. Several factors have contributed to the developing interest in Thailand in more efficient use of water resources, the most important being (a) the rapid increase of dry season cropping since the mid-1960s; (b) the introduction of rice varieties requiring higher water control standards; and (c) the completion of irrigation facilities for almost all irrigable areas in some river basins, under prevailing levels of water resource development. As a result, the Government of Thailand is now placing greater emphasis on operation and maintenance of the system and on water management in general. This study presents the findings and recommendations of a Bank and FAO/Cooperative Program mission which visited Thailand in March and June 1983 to gain greater knowledge of the constraints to irrigation system performance and to examine the potential for improving the system.

The level of performance achieved in managing irrigation projects depends on a number of physical, social and institutional factors and to a large extent on the physical infrastructure. Although irrigation in Thailand has some common features throughout, there is a great diversity of conditions among the country's four regions and among projects, depending on their size and historic development. This precludes any hasty generalization on present performance levels, and on recommendations for improvement of existing and new projects.

Irrigated Agriculture. Rice is by far the most important crop in Thailand in both the wet and dry seasons, but irrigated paddy accounts for only one fourth of the harvest compared to 40% in the Philippines and Indonesia and over 90% in Japan and Korea. Further, because of the limited scope for irrigation, the average annual yield remains one of the lowest in East Asia. Despite these unfavorable conditions, Thailand has for long been a major exporter of rice. However, with limited scope for opening up new irrigated lands and for economically developing more water resources, a major part of the production to meet Thailand's growing domestic rice demand and to maintain exports at current levels will have to come from higher yields on existing lands and better use of existing water resources.

Non-paddy irrigation in Thailand has so far been confined mainly to vegetables, fruits, and sugarcane in the North and the Central Plain. Aside from questions of marketing and profitability to the farmer, irrigation of upland crops is limited by the absence of operational procedures appropriate for these crops and by the physical condition of systems which makes such operations very difficult. With the exception of areas near urban centers for
fruit and vegetables and of the Mae Klong project for sugarcane, rice will most probably continue to be the dominant irrigated crop in both seasons throughout the country.

**Development of the Irrigation System.** Between the time of its creation in 1902 and 1980, the Royal Irrigation Department (RID) constructed large-, medium- and small-scale projects for gravity and conservation irrigation, drainage, and flood control. In 1980, construction was under way to serve an additional 760,000 ha.

Until the 1960s RID concentrated mainly on development of the Chao Phya Plain. In the Southern Chao Phya, which was developed before World War II, the canals were designed as flood relief channels to spread the flood waters more evenly. Following the war, the Northern Chao Phya was developed to provide semi-controlled irrigation. This extensive approach to irrigation system design was appropriate to provide supplemental irrigation during the wet season to the flat lands of the Chao Phya Plain. Its application to other regions with more irregular topography during the last 20 years was less successful.

A second generation of projects was initiated in the 1970s for the rehabilitation and extension of existing projects while at the same time using improved design standards for new projects. The major feature of these projects was the widespread introduction of higher standards of tertiary and on-farm development works to achieve a timely and reliable supply of water to farmers' fields. However, water delivery to the tertiary system was not improved as expected since the focus was primarily on on-farm development and related improvements required for the main and lateral systems were not sufficiently comprehensive and did not address the problem of unsteady flow conditions in the distribution system. It became apparent that improved water management can be achieved only after considering all the factors affecting irrigation performance.

In Thailand, the constraints on irrigation performance are in part related to unfavorable physical factors. The uneven pattern of rainfall causes a prolonged dry season, and optimal use of the water resources that are available is constrained by the relatively low potential for regulation. The Sirikit and Bhumipol Dams, for example, together control only 22% of the water in the entire Chao Phya Basin. Furthermore, these two major storage reservoirs are more than 300 km upstream of the diversion dam serving irrigable areas of the Central Plain. The large volume of uncontrolled flow causes deep flooding in the wet season, while the limited water available during the dry season poses a managerial problem of allocating water among water users and a technical problem of efficient system operation. Dry season irrigation is further hampered by sea water intrusion due to the tide in the Gulf of Thailand which affects the quality of water far upstream of the river mouths, and prevents water diversion for several weeks.

The other main constraints on irrigation performance in Thailand derive from the somewhat outmoded design of older parts of the system which were originally intended to supply supplemental wet season irrigation and thus lack the water control needed for modern irrigation. These constraints
include: (a) insufficient canal capacities for dry season irrigation in some projects; (b) the inability of individual turnouts to deliver adequate supply when not operating at full capacity; and (c) the difficulty of operating a large number of control structures which require frequent human intervention due to the instability of the system's hydraulic regime. Added to these deficiencies are: the incompleteness of some projects, especially medium- and small-scale systems which lack tertiary development; problems such as the lack of command, which result from designs based on inadequate mapping; and poor drainage which causes flooding in some project areas, and thus prevents significant water control in the paddy field. Most of these deficiencies are avoided in projects now being constructed.

Compounding the design and operational constraints is the generally poor state of system maintenance. Some projects are not in manageable condition and require minor to major repair. The rate of canal system deterioration is particularly serious in the Northeast where siltation and failure of the canal lining due to poor soil conditions are common. Aquatic infestation and removal of control structures by farmers also create operational problems throughout the country.

The combination of all these factors places an upper limit on the level of performance which management and operational staff are able to achieve. Water is excessive at some times and places and inadequate at others: the distribution system controls neither the timing nor the amount of water delivered and the on-farm water management practices are wasteful of water. With the exception of the main structures, there is little or no control of water flows in the system. However, because of the diversity of conditions, water management performance varies considerably from one region to another, depending on a variety of interacting physical and non-physical factors.

The Major Systems. RID has given special attention to the greater Chao Phya system which is by far the largest irrigation project in Thailand. Management of this system is complicated by the insufficient regulation of water resources and by the competition of irrigation needs with other requirements like energy generation. While the development of a computerized Water Management System (WMS) to coordinate water allocations in the basin has resulted in significantly improved irrigation efficiencies and reduced reservoir releases for dry season irrigation, the WMS is of little help in the day-to-day operations of a canal system. Nevertheless, RID has succeeded in establishing operating procedures for the main canal system, and performance levels are close to the upper limits attainable with the present control and communication infrastructure.

The Chao Phya's lateral and tertiary systems have been extensively studied in a series of reports prepared by RID. Problems in the gravity projects in the Northern Chao Phya are generally related to overuse of water and difficulties in maintaining gravity command. In the water conservation projects of the Southern Chao Phya, problems are generally related to inadequate security of water supplies and imbalances between available supplies and dry-season crop demands.
A high overall efficiency in the greater Chao Phya is attained during the dry season because of the combined effects of the irrigation and drainage systems which permit a substantial recovery of drained excess water for subsequent reuse. Yet there is considerable need to correct the inequality and untimely supply to farmers.

Despite a more favorable regulation of water resources, performance of the large-scale projects in the Northeast is much lower than in the Central Plain largely because of more difficult soil and topographic conditions. Low irrigation efficiencies are observed almost everywhere even in the most recently constructed or rehabilitated projects. RID, which has lately started a program to improve irrigation performance in the Northeast, recognizes that a large part of the mismanagement has to be attributed to the main system, which must be corrected prior to directing attention to on-farm water management. The Nong Wai Project, which benefited from this program, has now reached an adequate level of water management performance.

In practice there is little or no management of medium-scale projects in Thailand. These projects are also often incomplete and have an unregulated water supply.

An instructive contrast is provided by the management of private irrigation systems in the Northern Region which have been operated for centuries by local groups. There, the willingness of farmers to cooperate in maintaining irrigation works for the benefit of their community is particularly strong, especially where the water supply is abundant and reliable. Farmer groups organized in other regions for a similar purpose in large- and medium-size projects are not functioning well, largely due to the irregularity of water supply at the tertiary level which is not favorable to establishing cooperation among farmers.

System Improvements. Whether to rely on better management or to upgrade physical facilities in order to improve irrigation performance is a controversial question. As discussed above, the causes of inadequate water management are several and are not at all limited to deficiencies in institutions or budgetary shortages. The planning, design and construction process must produce a system capable of accommodating effective management practices. An inadequate system cannot be made to function adequately, no matter how good the management.

Better management would, of course, help to improve irrigation performance to some extent, although it will not solve all the problems of tertiary distribution.

(a) Improved management of water resources at the basin scale can dramatically increase cropping intensity, as has been proven by the success of the Water Management System in the Chao Phya project. Similar approaches should be generalized to the other large-scale projects benefiting from a regulated water supply. This would assist RID field staff in planning for future irrigation seasons and optimizing reservoir operations; and
(b) Orderly operation of the main canal system can also be achieved, as RID staff have demonstrated in the Chao Phya project, and the same level of performance could be attained in other projects with a regulated supply. However, an ongoing pilot management project in the Northeast seems to indicate that this requires a large number of dedicated and trained staff and a good communication network. At the same time, experience has shown the complexity of improving operations beyond the main canals because of the multiplicity of control points in the lateral and tertiary systems and the limitations of this approach.

Thus, with the increased number of completed projects, the progressive introduction of dry season cropping, and the long-term trend toward crop diversification in some areas, requiring higher standards of water control, RID is confronted with (a) the need for improved project operations with insufficient skilled staff, budget, transportation and communications; and (b) the need to find new approaches to irrigation operations for future projects. In its response to these needs, RID will need to select technologies for its future system improvement and development activities which can accommodate a great range of factors.

The preliminary step before choosing an appropriate technology for a project, whether a new project or improvement of an existing one, is the definition of the system's water management objectives. These may include:

(a) High efficiency in water distribution and productivity;
(b) High quality service to the water users;
(c) No negative environmental impact; and
(d) Equity and fairness of distribution.

Equity can be achieved either by apportioning the available water continuously according to fair users' rights or through fixed rotation depending on the variability of the supply. It requires simple infrastructure which can be operated with limited staff. However, such rigid distribution does not guarantee efficiency or maximum crop production.

The above four objectives are not easy to attain with outmoded systems, but systems can be modernized using various approaches now available to solve the crucial (and double) problem of canal regulation, i.e., water level and flow control. These approaches include localized upstream and downstream control, remote localized control and centralized control. Several technologies have been developed for these approaches which have been used and proven for the last 40 years. These techniques include equipment which automatically controls water level and flow and which is either hydraulically or electrically powered. Centralized control has the advantage that all control structures can be adjusted simultaneously rather than serially as in the case of localized control. A wide range of centralized control systems are possible, from the simplest remote monitoring control practiced in the Chao Phya to the most sophisticated one which is entirely computerized.
Centralized control and electrically-powered automatic equipment might well be suitable to modernize the main structures of existing large-scale systems like the Chao Phya, while simpler, hydraulically-powered equipment would be more suitable for canal regulation of medium- and small-scale projects. These techniques, of course, could be combined for the modernization of large-scale projects. Reduced staffing needs, simplified operations, increased efficiency and reliability of water supply, and subsequently increased agricultural production are the main advantages of these techniques. Although the design of irrigation systems using advanced technologies is certainly more complex, it could be progressively introduced in Thailand to achieve the higher water control standards required for modern irrigation of rice and for crop diversification. However, the wide range of objectives, concepts and technologies cannot be selected indiscriminately since they all have different financial and staff requirements for operation and maintenance, and different implications for the water users. The selection of concepts and technologies should therefore be carefully examined by planners and designers at the earliest stage of project preparation.

Both improved management of existing systems and their modernization should be accompanied by an institutional development program focusing on the training of RID operation and maintenance staff. But, as pointed out above, each approach to system improvement has different staff requirements. Improved management of existing systems requires more staff, more transportation facilities and a longer training period. On the other hand, the modernization process would require an extensive reorientation program, especially of design staff and, eventually, a team of specialists for operating and maintaining the more sophisticated system components, depending on the technologies adopted.

Maintenance. One of the pre-conditions for satisfactory operation of an irrigation system is obviously that it be maintained in acceptable operating condition. Thailand's irrigation system has generally not been well maintained, but Government is now placing greater emphasis on correcting this problem. It should be recognized, however, that the operation and maintenance (O&M) of a system are very much influenced by project planning, design and construction which can either facilitate O&M or increase the amount of O&M needed.

A substantial part of the current maintenance program in Thailand includes construction of new works such as tertiary development to complete existing projects. These works, and even part of RID's tremendous program of deferred maintenance, should be carried out by the RID Construction Division since the scope of works surpasses normal maintenance activities.

Maintenance requirements can vary considerably from one project to another depending on several factors, e.g., the age and type of structure, soil conditions, water quality, degree of weed infestation and quality of construction. The criteria to determine staff and budget requirements for maintenance should not be related to areas served, but to actual maintenance needs.
It is recommended that both major and minor works should be examined regularly as follows:

(a) Examination prior to the acceptance of works executed by contractors is routinely done by RID construction engineers. Another formal examination should be done at the time of transfer of completed facilities, including those built by force account, from a construction status to an operation and maintenance status, i.e., when the responsibility for care is passed from the Construction Division to the Operations Division. A period of up to two years might elapse during which corrective measures could be taken if necessary; and

(b) Preventive maintenance is not currently undertaken in RID's maintenance programs because of the cumulative volume of deferred repair and maintenance works. It is recommended that RID begin a program of examination and preventive maintenance of new and recently rehabilitated projects.

Finally, RID should determine how to encourage more communications within the Department. A system is needed whereby design and construction staff get feedback from operation and maintenance staff so that problems caused by inappropriate design and poor construction practices could be highlighted. Participation of staff from all relevant technical divisions in the regular examination of irrigation facilities might also help to increase awareness of the need for some form of modernization and to accelerate the process of system improvement.

The Tertiary System. The design of on-farm development works and tertiary systems is a matter of considerable discussion and experimentation in Thailand. In the 1970s intensive tertiary development was recommended in response to poor on-farm irrigation performance. It has become clear, however, that the intensity of the tertiary network itself does not correct the problem of inadequate supply at the farm turnout, and may not result in substantial improvements in irrigation performance unless the main system is improved simultaneously. Many water management problems at the tertiary level are instead caused by supply problems in the main system. For example, low water use efficiencies at the tertiary level are largely a result of over-supply through many farm turnouts. In contrast, service areas located toward the tail end of laterals do not receive the full benefits of irrigation due to low and unreliable supply.

A further complication to the problem of tertiary system distribution is the emerging trend toward crop diversification in some regions. Irrigation of diversified field crops on a large scale raises many questions which have not yet been fully resolved. First, diversified field crops do not accommodate over-irrigation and continuous irrigation, which are common practices in irrigating rice in Thailand. Second, these crops should be promoted only where they have a comparative advantage. This would be in much of the Northeast and the Mae Klong Project areas, but not those parts of the Central Plain with heavy soils and a susceptibility to flooding. Third, diversified field crops require a system of shared water use at the farm level, supported by an intensive tertiary network.
In response to these various needs, since the mid-1970s RID has promoted the concept of rotational irrigation, a comprehensive land consolidation program and several other system improvements. To date, however, these innovations have had mixed success in improving the delivery of irrigation water to the farm.

Rotational irrigation has been tried in several projects but the results have generally been disappointing. Experience has indicated that the implementation of this distribution method will not be effective until adequate and reliable water is supplied at the farm level. For example, in rice areas which receive much more water than required, farmers have insufficient incentive to organize the distribution of water within the service area; and when water is supplied erratically or at rates significantly less than the minimum requirement, divisive forces among farmers break down the cooperation necessary for them to share water equitably.

While a rotational system of tertiary irrigation is required for diversified cropping and may have some advantages over continuous irrigation for rice, its implementation is contingent upon a set of preconditions, few of which now exist in Thailand. The most important of these preconditions are: (a) reliable flows through the farm turnout, (b) an operations plan for the network, (c) installation of measuring and control structures, (d) agricultural extension services, and (e) strong and sustained political commitment.

The most successful form of rotational irrigation in Thailand at present was developed in the Nong Wai Pioneer Agriculture Project. But this experience is not totally replicable since abundant water supply conditions in the project area are particularly favorable to the introduction of this distribution method. Further, the project provides a rotated water supply to groups of about ten farmers at a time, but this is not appropriate for diversified cropping which requires water delivery to individual farmers.

Other attempts to improve tertiary distribution have also been relatively successful. The land consolidation program in the Chao Phya has played a critical role in promoting dry season cultivation of rice. However, the program became popular not so much because of increased paddy yields but because of higher land values since consolidated areas received preferred access to scarce dry-season water. Some success has also been achieved by reducing the size of tertiary service areas to 40-50 ha each, and in using an annual rotation for dry season irrigation. The latter has allowed scarce water to be used more productively and efficiently.

The lack of a reliable water supply discussed above also affects farmer organization at the tertiary level. Water user groups are expected to cooperate in the equitable distribution of water, maintenance of the on-farm system and payment for irrigation services. But it is doubtful that, unless water delivery meets farmers' needs, they will be willing to cooperate for these purposes. At a minimum, farmers should have some control over the water delivery schedule.
I. BACKGROUND

1.01 Like several other old irrigation systems in the world, the Thai irrigation system has served the objectives of its designers remarkably well, that is, it has benefited as large an area as possible, bringing new land into production and reducing drought and flood risk on cultivated land. This extensive approach to irrigation development involved low standards of water control at the farm and distribution system levels and was justified at a time when many of the factors requiring a high degree of water control (e.g., scarcity of water, crop technology, crop diversification) were absent.

1.02 More recently, however, with limited scope for opening up new irrigated lands and for economically developing more water resources, a major part of the production to meet Thailand's growing domestic rice demand and to maintain export levels has to come from higher yields on existing lands and better use of existing water resources. Thus in the 1970s, most of the large increase in rice production came from development of dry-season irrigation, especially in the Central Region which had the greatest potential for increasing irrigated rice production. In the late 1970s consultants of the Royal Irrigation Department (RID) concluded that the most promising way to make water available for further development in the Chao Phya Basin was to reduce the rate of water use for irrigation. This conclusion was valid for most other basins in Thailand as well.

1.03 Thailand's existing irrigation system was determined by the country's physical characteristics, particularly its water resources, climate and soils, and the cropping patterns appropriate to the physical situation. As this chapter points out, Thailand is well endowed with extensive river basins, but is subject to an annual dry season lasting five to six months and, in some years, inadequate rainfall year-round. Irrigation facilities have been developed to compensate for this irregular rainfall pattern.

Regions and River Basins

1.04 The resources, socioeconomic conditions and production potential of Thailand's four major regions - North, Central, Northeast and South - vary considerably from region to region (See Annex 1 for details of the resource base). Historically, economic development has tended to concentrate along the major rivers of the Central Region, a trend which has been reinforced over the past century by the growth of Bangkok as a major port and commercial center. Development of the other regions followed construction of the railways and, in the past 25 years, the extensive highway network. Nevertheless per capita incomes in the other regions still lag behind those in the Central Region.

1.05 The water resources of the regions have been and will continue to be a key factor in their economic development. The Chao Phya Basin, the largest and most important geographic unit in Thailand in terms of land and water resource development, covers a large area in both the North and Central Regions (Map IBRD 17012R1). Four northern tributaries, the Ping, Wang, Yom and Nan, join together at Nakhon Sawan about 200 km north of Bangkok to form...
the Chao Phya River. After following a single course for about 60 km, the River splits into three branches which flow across the Chao Phya Plain to the Gulf of Thailand. The Chao Phya Plain contains one of the world's largest networks of navigation, drainage and irrigation canals, some dating back to the 1890s. Two major dams have been constructed on the Ping and Nan to store water for irrigation and generate hydroelectric energy.

1.06 The country's second largest river basin in terms of size and development potential, the Mae Klong, is also in the Central Region to the west. The Quae Yai and Quae Noi Rivers rise near the Burma border and join together to form the Mae Klong, some 80 km from the Gulf of Thailand. Canal systems here are at an earlier stage of development than those in the Chao Phya Basin. A major multipurpose dam was recently completed on the Quae Yai. The Central Region also includes the Bang Pakong Basin, a major part of which is a southeast extension of the Chao Phya Plain.

1.07 The Northeast Region has fairly well-defined physical boundaries; the Mekong River to the north and east, and mountain ranges to the south and west. Virtually all of the region is drained by tributaries of the Mekong (Map IBRD 17452). The Southern Region extends from the west of the Mae Klong Basin to the Malaysia border. Most of its land and water resources are on the east coast. Major river basins are the Pattani and Ta Pi-Phun Duang (Map IBRD 17453). Basic hydrological data for the major river basins are presented in Table 1.

Climate

1.08 Thailand's climate is tropical and monsoonal, characterized by rather high humidity year-round and a markedly seasonal distribution of rainfall. Temperature is high and relatively uniform throughout the year in all regions and is generally favorable for year-round crop production. Peak temperatures usually occur in March and April with lows from November through January. In the Central, Northern and Northeast Regions altitude modifies temperature considerably; in the northern highlands it is cool enough to produce temperate fruits and vegetables and vegetable seed. There is little variation in day length, and radiation levels are generally satisfactory for maximizing yields, except for the Southern Region during the wet season.

1.09 The Northern, Central and Northeast Regions are subject to the southwest monsoon, which begins any time from late April to June. The monsoon carries moist warm air over all three regions but the amount of precipitation is greatly affected by mountains. The Mae Klong area and the lowlands west of the Chao Phya Plain are sheltered on the west by mountain ranges, and so barely receive 1,000 mm of rainfall a year. The east coast near Rayong, however, is exceptionally wet where the monsoon strikes the mountains bordering Kampuchea. Since the three regions are sheltered by high mountain ranges on the north and by the Annamite Cordillera on the east, there is a pronounced dry period during the northeast monsoon period which lasts from November to March (see box on Map 17452 for annual rainfall). Average annual rainfall from the southwest monsoon ranges from just above 1,000 mm in the lowlands on the leeward side to about 1,500 mm on the windward side. About 85% of this rainfall occurs between mid-May and October. While total rainfall during the
major rice-growing period is sufficient to meet requirements during a normal year, shortages occur during years of subnormal or irregular rainfall. In the five- to six-month dry season, it is impossible to grow a second crop without irrigation.

1.10 The Southern Region has a markedly different climate from the other regions, particularly with respect to rainfall amount and distribution. By being subject to both the southwest and the northeast monsoons, annual rainfall in the region is high, ranging from 1,800 mm to more than 3,500 mm, depending on the location. The dry season in the South lasts no more than two to three months. Southeast Thailand is also subject to typhoons which originate in the South China Sea and travel westward. The rest of Thailand, however, is shielded from the typhoons by mountains on the east.

1.11 Although Thailand's temperature is favorable to year-round production, the rainfall amount and distribution limit the cultivation of rice, the predominant crop, and to some extent the production of other crops to the wet season. With the exception of the Southern Region, rainfall conditions in Thailand are less favorable than those in other countries in the region like Taiwan, Viet Nam, Indonesia and Malaysia which benefit from an annual rainfall of about 2,000 mm or more (see Table 1.1), and a dry season two or three months shorter than that of Thailand.
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<td>(25-year average)</td>
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<td>66</td>
<td>156</td>
<td>136</td>
<td>104</td>
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<td>29</td>
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<td>117</td>
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<td>Nyaunggyat</td>
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<td><strong>Korea</strong></td>
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<tr>
<td>South-Yong San Gang</td>
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<td>40</td>
<td>65</td>
<td>90</td>
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<td>175</td>
<td>50</td>
<td>50</td>
<td>35</td>
<td>1,240</td>
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</table>
Soils

1.12 Most of the irrigable areas in Thailand are in the flood plains of the major rivers where a combination of heavy rainfall and overbank flooding precludes the cultivation of crops other than paddy in the wet season. In the Chao Phya Plain, heavy soils predominate and paddy is the preferred crop in the dry season as well. The situation is similar in the coastal plains of the South. Dry season cropping is more diversified on the alluvial soils of the North, and in the small area developed for irrigation in the Northeast.

Cropping Patterns and Production in Irrigated Areas

1.13 Rice is by far the most important crop in Thailand in both rainfed and irrigated areas. Wet season rice predominates since it is the only crop able to withstand the annual periods of flooding. Rice is also relatively well adapted to the heavy clay soils of the Central Plain and North, and to the less fertile river valley terraces in the Northeast.

1.14 The total planted rice area grew steadily from 5.5 to 9.5 million ha over the last 20 years. Only one fourth of this area is irrigated; nearly 4.5 million ha or 45% of the total planted area is in the Northeast and is practically all rainfed. Data on rainfed and irrigated paddy production by year, region, etc. are given in Tables 2-4.

1.15 Annual rice production stagnated in the 1960s between 10-11 million tons then rose rapidly in the 1970s in response to the release of high-yielding varieties (HYVs) and improved water supply in the Central Plain after completion of two major storage dams (para. 2.04). Future growth is expected to be much slower.

1.16 Average paddy yields in planted areas have stagnated at 1.8 ton/ha, largely because of the preponderance of rainfed rather than irrigated paddy. For wet season paddy, yields average 1.2 ton/ha in the Northeast, 1.8 ton/ha in the Central and Southern Regions and 2.3 ton/ha in the North. For irrigated rice the average yields grew from 2.8 ton/ha in the early 1970s to 3.8 ton/ha at present although yields vary significantly and range between 2.6 tons/ha in the South and Northeast, 3.5 ton/ha in the North, and 3.9 ton/ha in the Central Plain. Yields of 3.8 and 4.1 ton/ha have been obtained in the wet and dry seasons, respectively, in areas benefiting from intensive on-farm development with improved water management and effective supporting services. However, because of the limited scope for irrigation development in Thailand, especially in the Northeast, the average annual yield will continue to remain one of the lowest in East Asia. Annex 2 provides a more detailed discussion of the water requirements of rice and the effects of rice cropping practices, particularly as they are influenced by irrigation system operations.

1.17 The irrigated paddy area accounts for only 25% of the harvest in Thailand but reaches 40% in the Philippines and Indonesia and over 90% in Korea and Japan. Still, despite the comparatively limited irrigated rice area, the low yields, as well as a reliance on rice as its main food staple and a very high per capita consumption of rice, Thailand led the world in rice
exports during the 1970s and still provides 20-25% of total world exports. This has been possible because, of the six major countries in East Asia (excluding China), Thailand has the lowest ratio of population per area harvested (5.3 capita/ha compared to over 50 capita/ha in Japan) and the largest area harvested (Table 1.2).

Table 1.2: PADDY PRODUCTION IN EAST ASIA, 1981

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<th>Thailand</th>
<th>Burma</th>
<th>Indonesia</th>
<th>Philippines</th>
<th>Malaysia</th>
<th>Korea</th>
<th>Japan</th>
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<tbody>
<tr>
<td>Population (millions)</td>
<td>48</td>
<td>34.1</td>
<td>149.5</td>
<td>49.6</td>
<td>14.2</td>
<td>38.9</td>
<td>117.6</td>
</tr>
<tr>
<td>Area harvested ('000 ha)</td>
<td>9,140</td>
<td>5,500</td>
<td>9,005</td>
<td>3,500</td>
<td>762</td>
<td>1,224</td>
<td>2,278</td>
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<tr>
<td>Paddy production ('000 tons)</td>
<td>19,000</td>
<td>14,636</td>
<td>33,000</td>
<td>7,720</td>
<td>2,147</td>
<td>7,032</td>
<td>12,824</td>
</tr>
<tr>
<td>Paddy yield (ton/ha)</td>
<td>2.07</td>
<td>2.66</td>
<td>3.66</td>
<td>2.20</td>
<td>2.81</td>
<td>5.74</td>
<td>5.63</td>
</tr>
<tr>
<td>Population (capita/ha)</td>
<td>5.3</td>
<td>6.2</td>
<td>16.6</td>
<td>14.2</td>
<td>18.6</td>
<td>31.8</td>
<td>51.6</td>
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<tr>
<td>Area harvested</td>
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<tr>
<td>Paddy Production</td>
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<tr>
<td>(kg/capita)</td>
<td>395</td>
<td>429</td>
<td>220</td>
<td>155</td>
<td>151</td>
<td>180</td>
<td>109</td>
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<tr>
<td>Irrigated Area (%)</td>
<td></td>
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<tr>
<td>Total harvested area</td>
<td>25</td>
<td>16</td>
<td>38</td>
<td>40</td>
<td>62</td>
<td>91</td>
<td>96</td>
</tr>
<tr>
<td>Export ('000 tons)</td>
<td>3,138</td>
<td>699</td>
<td>0</td>
<td>94.7</td>
<td>0</td>
<td>0</td>
<td>855</td>
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<tr>
<td>Import ('000 tons)</td>
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<td>0</td>
<td>0</td>
<td>12</td>
<td>340</td>
<td>2,585</td>
<td>75</td>
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</table>

1.18 Irrigated Upland Crops. Vegetable and fruit crops are grown near Bangkok, and sugarcane is found on lighter and more steeply sloped terraces. There is little scope for non-paddy crops in the major irrigation commands during the wet season, when diversified cropping is risky and is confined largely to special crops and markets.

1.19 Irrigated dry season upland crops are currently grown on only about 40,000-50,000 ha. Diversified cropping in the dry season has been practiced for many years in parts of irrigated commands of the North, and more recently in limited parts of the Central Plain and Northeast. Soybeans, groundnuts, and tobacco are popular in the North, groundnuts and corn in the Northeast, and sugarcane in the Central Plain.

1.20 Of the several crops which have been produced profitably under irrigation, sugarcane is the most important. Thailand's exports of sugar rank within the top six countries worldwide, and considerable land shifts between rice and sugarcane depending on relative prices of the two products. The
growth of sugarcane production was extremely rapid during the 1970s, from about 160,000 ha in 1970-71 to about 560,000 ha by 1977-78. Only part of the expansion was in areas supplied with public irrigation systems. During recent years, the area planted to sugarcane has contracted somewhat and stabilized. Future prospects for the crop are closely tied to the large production subsidies currently paid by the Government, which are now being questioned. Much of the former rice land now producing sugarcane may revert to rice if the subsidy is significantly reduced or removed.

1.21 Maize is grown on about 1.5 million ha, but almost none of it is under irrigation. Thailand has lost most of its major export market, Japan, but has compensated to a large extent in the rapidly expanding domestic feed industry. Because current yields are relatively high (2.1 t/ha), there is little prospect for maize becoming an important irrigated crop.

1.22 Mungbeans, soybeans and groundnuts are grown on about 500,000, 130,000 and 100,000 ha, respectively. Mungbeans are sometimes grown on residual moisture following an initial application of irrigation prior to sowing. Irrigation throughout the dry season is more important for soybeans and groundnuts, especially the latter. Some of the larger irrigation systems of the North are widely planted to mungbeans, soybeans or tobacco during the dry season, but usually only one of these crops dominates the cropping pattern of any one system. Groundnuts have increased rapidly as an irrigated dry season crop in the Northeast, and represent perhaps the most promising possibility for further increases in irrigated areas. About 75% of the planted area of the Lam Pao project is now devoted to this crop in the dry season. The average yield of groundnut is about 1.3 t/ha, compared with about 2.0 t/ha under irrigation. Its water requirement is less than half that of rice, and should be supplied in four to six discrete stages of crop development.

1.23 Constraints to Crop Diversification. In principle, irrigation of upland crops has decided advantages. Diversified crops with the exception of sugarcane require much less water than does rice. The water requirement of rice is so high that only a portion of the total irrigable area can be adequately supplied during the dry season because of the limited water resources - about 35% of the greater Chao Phya project, 70% of the Mae Klong project, and about 50-70% or more of the large reservoir projects in the Northeast. By switching the dry season crop from rice to groundnut, soybeans or other upland crops, at least twice the current dry season area could be irrigated. On the other hand, the soils and topography in irrigated areas usually do not favor upland crops, and markets are not yet developed for them because of the highly competitive nature of the Thai agricultural economy and the doubtful prospects of their profitable production under irrigation. The decisive factor, however, is the low level of water control allowed by the existing irrigation systems which are designed and operated for the specific needs of rice.

1.24 Rice does well with a continuous supply of water, which is the normal mode of supply in almost all Thai irrigation systems, whereas upland crops require scheduled periods of irrigation and drying out. Rice fields are a satisfactory medium for conveying water from areas near supply points to the farther fields, whereas upland crops must be supplied by an intricate network of field channels to protect against flooding. Graded furrows or other con-
veyance systems may also be necessary within farm plots for upland crops. Rice does best in the tropics under saturated soil conditions which are completely unsatisfactory for all upland crops. Thus, farmers considering a shift from rice to upland crops in the dry season would be deterred by the problems of water control and the additional labor required for on-farm water management. It should be noted, however, that the basic design concepts for effective management of the main and distribution systems are not affected by the nature of the crop. It is only the tertiary and on-farm development systems which would have to be progressively adapted and intensified to fit the specific requirements of upland crops.

1.25 It is also difficult for a farmer to irrigate both rice and upland crops simultaneously since lateral seepage from rice land and canals sometimes creates saturated soil conditions on land otherwise suitable for an upland crop. To irrigate both rice and upland crops under the same farm turnout (FTO) usually results in unsuitable irrigation for both (too much for upland crops or too little for rice) and thus lower yields. A 1975 study conducted in representative tertiaries of the Mae Klong project area found paddy yields of 2.2 t/ha from service areas in which sugarcane was not planted, and 1.6 t/ha where paddy and sugarcane were planted within the same service areas. Average yields of sugarcane were 40 t/ha from service areas wholly planted to that crop, and 29 t/ha for areas planted to both paddy and sugarcane. Both crops yielded 38% more when planted alone compared with their yields when grown together in the same service areas. This difference would be even more marked for crops other than sugarcane because their optimum water regimes are less than that of sugarcane.

1.26 In summary, rice will most probably continue to be the dominant irrigated dry season crop throughout the country. The remarkable increase in the area under dry season irrigation in the Central Plain, which occurred in the 1970s and early 1980s (para. 2.15), in conjunction with farmers' adoption of modern rice varieties with relatively quick maturity (100 to 120 days growth duration) and high potential yield in the dry season (over 4.0 t/ha) not only makes rice farming more profitable, but also generates much greater returns to investments in irrigation.

1.27 The profitability of growing upland crops under irrigation is jeopardized, at least in the short run, by the absence of operational procedures for the main system appropriate for those crops, and by the physical condition of the network which makes such operations very difficult. The cost of adapting large-scale systems to supply water properly to upland crops is high. Some upland crops will continue to be grown on residual moisture, however, and there will be more diversified cropping in the smaller systems of the North where farmers have a relatively strong influence on how water is supplied (para. 4.25). Some expansion is likely in the Northeast as well. With the exception of limited areas of fruit and vegetables near Bangkok, and sugarcane in the Mae Klong project area, irrigated upland crops do not have a comparative advantage in the Central Plain (see Annex 2, for further discussion on crop diversification).
2 IRRIGATION DEVELOPMENT IN THAILAND

Historical Background

2.01 The first large-scale water control projects in Thailand were begun as private enterprises in the Chao Phya Plain in the 1890s. In 1902, the Royal Irrigation Department (RID) was established as the agency responsible for water resource development throughout Thailand. Although no longer responsible for hydroelectric development, which is now handled by the Electricity Generating Authority of Thailand (EGAT), RID handles virtually all irrigation development in Thailand, except for the numerous small private schemes in the Northern Region developed by farmer groups (People's Irrigation Projects) within the last two centuries (para. 4.25).

2.02 In developing the Chao Phya Plain, RID used an extensive approach to modify the natural flood regime over large tracts of land. In southern Chao Phya, which is subject to deep and prolonged flooding, canals were designed as flood-relief channels to spread the floods more evenly and to promote drainage at the end of the flood season. In northern Chao Phya, drought is more of a constraint to rice production than floods, and therefore diversion dams and irrigation canals were designed to provide semiconrolled inundation.

2.03 Through the 1930s more than 500,000 ha in southern Chao Phya were developed through the construction of navigation/drainage canals. This development resumed in the 1950s when canals were built to serve nearly 200,000 ha in the adjacent Bang Pakong Basin. In recent years low-lift pump irrigation has spread widely in these areas during the dry season.

2.04 In 1950 RID began a program to develop gravity irrigation systems covering 600,000 ha in northern Chao Phya; the program continued through the 1960s. In 1956 the Chao Phya barrage, also called the Chainat Dam, was completed, permitting flow diversion of the Chao Phya River. Construction of the Bhumiphol Dam was completed in 1964 as a first step in controlling the flow of the Chao Phya's northern tributaries. This was followed by the Sirikit Dam completed in 1972. Construction of these two reservoirs greatly increased the amount of water available in the dry season.

2.05 Over the past 20 years RID also began to develop other river basins and regions. A 120,000 ha first-stage gravity irrigation system and a 30,000 ha drainage system were constructed in the Mae Klong Basin. In the Northeast, seven large reservoirs and main canals were constructed. Numerous smaller schemes were also built in the North, Northeast and South. The extensive gravity approach used in the northern Chao Phya system in the 1960s was also used in projects outside the Central Region despite the large variety of soils and uneven terrain found in those areas. These projects were generally unsuccessful and indicated the need for much higher standards of design and mapping.

2.06 The circumstances that favored the extensive approach to irrigation changed in the mid-1970s with the introduction and rapid development of dry season rice cultivation as well as new rice varieties and farming practices,
all of which required higher water control standards. The keen competition for dry season water encouraged farmers to cultivate upland crops which have lower water requirements than rice but need more controlled water delivery. It was realized at that time that further exploitation of Thailand’s irrigation potential would require much more emphasis on reliable and timely delivery of water to the farmers’ field and this would involve upgrading virtually all existing irrigation systems and incorporating higher standards of water control when expanding existing systems and constructing new projects.

2.07 A second generation of projects was therefore initiated in the mid-1970s for the rehabilitation and extension of existing projects while at the same time using improved design standards for new projects. The major feature of these projects was the widespread introduction of higher standards of tertiary and on-farm development. Design of the main systems was not appreciably altered. About 90,000 ha in northern Chao Phya were improved through implementation of on-farm works ranging from single tertiary ditches to intensive development to serve each farm with ditches, drains and roads. A new project serving 97,000 ha in Phitsanulok Province with similar standards is now being completed. Other extension and rehabilitation projects are under way in the Northeast Region and the Mae Klong Basin.

2.08 RID is also responsible for implementation of small-scale projects. In 1977, this program was accelerated to benefit as many localities in the country as possible. Small-scale irrigation works are designed to develop all types of water sources to meet farmers’ water needs for household consumption and agriculture. More than half of the total number of small-scale projects are located in the Northeast.

Present Situation

2.09 The 1980 inventory of RID projects indicated that existing projects covered a total service area of 2.88 million ha, which was 500,000 ha larger than the area served in 1976. At the same time, construction was under way to serve an additional 760,000 ha. Irrigation development broken down by RID region and river basin is summarized in Tables 5 and 6.

2.10 The major part of this development was through large-scale projects with service areas exceeding 20,000 ha. The nine largest projects serve 1.66 million ha or 62% of the total area now covered:

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1/ A survey of a 10% random sample from a population of 1,400 projects completed in 1980 showed that 85% are used for irrigation, 65% have storage facilities and 17% distribution facilities.

2/ "Water Resources Development in Thailand," Statistics and Program Report Section, RID, December 1980. A recent article published on the occasion of the 81st anniversary of the Department mentioned that in 1982 RID had completed a total of 2,833 projects benefiting approximately 3.86 million ha including: (a) 478 large- and medium-scale projects serving 3.3 million ha; and (b) 2,350 small-scale projects serving 0.56 million ha.
Greater Chao Phya 1,080,000 ha
Mae Klong Stage I 175,000 ha
Phitsanulok 97,000 ha
Nakhon Nayok in Bang Pakong Basin 92,000 ha
Petchaburi 55,000 ha
Pattani 50,000 ha
Lam Pao 44,000 ha
Pranburi 35,000 ha
Nam Pong 33,000 ha

With the exception of those in the Bang Pakong Basin, all the large-scale projects benefit from some regulation of water resources by large storage reservoirs.

2.11 About 110 medium-scale projects having service areas ranging from 1,000-20,000 ha were inventoried in 1980 (see Table 7). A further 50 are currently being constructed. Of the 430,000 ha served by existing projects, only one fourth benefit from regulated flow through storage reservoirs. Seventy percent are in run-of-river projects and 5% in pump projects. Eighty percent of the storage projects are in the Northeast. As of 1982, more than 2,350 small-scale projects serving 560,000 ha were completed. The pace of construction is about 500 projects per year.

2.12 A Bank estimate in 1976 of the irrigable areas in existing projects was about 300,000 ha below the RID estimate. The difference was largely due to the Bank's much lower estimate of the areas benefiting from irrigation systems in the Mae Klong Basin and the Northeast. A detailed inventory of irrigable areas would likely indicate an even greater difference for the following reasons:

(a) Part of the irrigation facilities for some projects inventoried as complete have not yet been built. This is particularly true for medium-scale projects which have often been provided with only a diversion structure or a section of the main and lateral canals.

(b) A substantial part of the service areas of gravity irrigation projects are out of command even when canals are running at full supply.

2.13 Wet season irrigation provided some degree of beneficial water control over an estimated 2.4 million ha in 1979/80, including 2.1 million ha of paddy in RID projects, 3/ 0.2 million ha in People's Irrigation Projects, and 50,000 ha of sugarcane and vegetables in both project areas. About 70% of

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3/ Not including about 0.2 million ha of floating rice.
the paddy area benefits from gravity irrigation systems and 30% from navigation/drainage canals.

2.14 There was a difference of nearly 500,000 ha between the service areas of existing projects (2.88 million ha) and the areas irrigated during the wet season (2.4 million ha) in 1980. This difference is partly due to the shift from wet season to dry season cropping on about 100,000 ha in southern Chao Phya which are deeply flooded and not planted during the wet season. The remaining 400,000 ha may be due to incomplete projects, lack of command of some areas, rights-of-way and more generally to the unclear definition between areas benefiting or not from irrigation water during the wet season (i.e. floating rice).

2.15 **Dry season irrigation** was initiated in 1965 and increased slowly to 92,000 ha in 1972. After a six-year period of rapid expansion, it covered 475,000 ha, which is close to the attainable limit with the present infrastructure and water use efficiency. About 80% of the dry season cropped area is located in the Central Plain and contributes about 85% of the total dry season production. Although most development effort has been directed to the northern Chao Phya plain, over 60% of the dry season cropped area is in the southern Chao Phya where farmers grow an irrigated dry season crop by pumping from navigation drainage canals, rather than growing a high-risk, low-yielding broadcast wet season crop in these flood-prone areas.

3. **CONSTRAINTS ON IRRIGATION PERFORMANCE**

3.01 This chapter discusses the problems generally affecting the various irrigation systems in Thailand and in so doing provides a context for the discussion in Chapter 4 of the performance of specific major projects and project regions. The constraints on irrigation performance in Thailand are in part related to unfavorable physical conditions, i.e., its limited water resources due to the pattern of rainfall, and flooding in the low lying lands of its river basins. The other main constraints derive from the somewhat outmoded design of older parts of the system which were originally intended to supply supplemental wet season irrigation, and thus lack the water control needed for more modern irrigation regimes. These problems, both singly and in combination, affect the performance of Thailand's existing irrigation systems, and represent the challenges to be met in future development of the systems.

A. **Limited/Unregulated Water Resources**

3.02 **Limited River Flows.** Thailand's uneven and for the most part limited pattern of rainfall described in paras. 1.08-1.11 is reflected in the river flows. The large rivers start to rise following the onset of the southwest monsoon and are affected by the high precipitation covering large areas until October; they then recede rapidly during the dry season. The small rivers more closely follow the pattern of local rainfall, with sharp recessions in flow coinciding with drought periods. Runoff per sq km is much higher in the mountainous areas of the Northern and Southern Regions because of the more abundant rainfall and other positive factors such as soil and topography of the catchment (see Table 3.1).
Table 3.1: RAINFALL RUNOFF BY REGION

<table>
<thead>
<tr>
<th>Region</th>
<th>River</th>
<th>Catchment area (sq km)</th>
<th>Annual rainfall (mm)</th>
<th>Annual runoff (mcm)</th>
<th>Specific runoff (mcm/sq km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper North</td>
<td>Mae Sai</td>
<td>965</td>
<td>1,673</td>
<td>677</td>
<td>0.70</td>
</tr>
<tr>
<td>Lower North</td>
<td>Khlong Tron</td>
<td>469</td>
<td>1,305</td>
<td>123</td>
<td>0.26</td>
</tr>
<tr>
<td>Central</td>
<td>Lam Sonthi</td>
<td>1,247</td>
<td>1,167</td>
<td>231</td>
<td>0.18</td>
</tr>
<tr>
<td>Northeast</td>
<td>Lam Takhong</td>
<td>1,340</td>
<td>1,100</td>
<td>250</td>
<td>0.18</td>
</tr>
<tr>
<td>South</td>
<td>Khlong Yan</td>
<td>1,181</td>
<td>2,200</td>
<td>1,528</td>
<td>1.29</td>
</tr>
</tbody>
</table>

During the dry season, the flow of most rivers in the lower North Central Plain and Northeast Region virtually ceases while a flow of 5-7 liter/sec per sq km is maintained in the Upper North and the South. The prolonged dry season has a major impact on cropping intensities. In areas of Southeast Asia where the difference in rainfall during the wet and dry seasons is less pronounced, cropping intensities during the dry season are very high. In Java and Taiwan, for example, they exceed 50% and 100% respectively, compared to an average of 20% in Thailand.

3.03 The large seasonal fluctuations of natural flow have been partly overcome through storage reservoirs which permit flow regulation and year-round irrigation. During the dry season, the natural flow is sufficient to irrigate only a fraction of the area irrigated in the wet season. In the Upper North, paddy or an equivalent of upland crops is cultivated on about 20% of the irrigable area. In other regions less than 10% of the area, if even that, is irrigable. But even during the wet season, storage dams are essential for irrigation in the entire Northeast and those parts of the Central Region not in the major river areas, because of the sharp flow recessions during dry spells.

3.04 RID and more recently EGAT have built a large number of storage dams in Thailand. About 25 have a capacity exceeding 50 million cu m (see Table 8). The major dams are the Bhumipol on the Ping River, Sirikit on the Nan River in the Chao Phya Basin, Srinagarind on the Quae Yai and Khao Laem on the Quae Noi in the Mae Klong Basin, Uboiratana and Lam Pao Dams in the Northeast and Bang Rang on the Pattani River in the South. Construction of the Chiew Larn dam in the Ta Pi Basin for the Southern Region is just starting. Construction of other dams on the Upper Quae Yai and on the Mae Yom and Mae Kok Rivers is also under consideration by EGAT. After that, there will be little scope to increase the regulation of water resources. Interbasin diversion of water from the Mekong River to increase resources for the Central and Northeast Regions has been considered, but these projects raise economic and riparian issues. The other alternative, and the one discussed in this report, is to develop the important potential offered by improved use of existing water resources.
Limited Flow Regulation. The construction of storage dams has helped to compensate for the vagaries of the monsoon rainfall in the wet season and has substantially increased the availability of water in the Central Region and in the Northwest during the dry season. However, because the main reservoirs are located in the upper basins of the major rivers and their tributaries, they control only a fraction of the natural flow. Together, Sirikit and Bhumiphol Dams control only 39,600 sq km or 32% of the catchment area of the Chao Phya River at the confluence of the Ping and Nan Rivers at Nakhon Sawan upstream of the Chao Phya diversion dam, and 22% of the total catchment area. About half of the natural flow at Nakhon Sawan is uncontrolled. The two storage reservoirs, Srinagarind and Khao Laem, together control 42% of the catchment area at the Vajiralongkorn diversion dam on the Mae Klong River. On the other hand, the runoff from the drainage areas upstream of the reservoirs can be almost completely controlled because of large storage capacities.

The irrigation areas served by canals emanating directly from storage reservoirs, such as the Lam Pao project, or from a diversion pond not far downstream, as in the Mae Klong and Nam Pong projects, benefit from a much higher degree of regulation of their water resource than the projects located far downstream of the reservoirs. These semiregulated water resources are sufficient to supply only about 35% of the irrigable area in the Chao Phya Plain during the dry season after full development of the Phitsanulok Project, while about 60% of the Lam Pao and 70% of the Nam Pong project areas can be irrigated in the Northeast. The most favorable situation is in the Mae Klong Basin where a cropping intensity of about 70% can be achieved during the dry season while a flow of nearly 50 cu m/sec can still be diverted from this basin to the water-deficient Chao Phya Basin.

Conclusion. The degree of regulation of water resources in Thailand varies substantially from one irrigation project to another. This basic factor should be given far more attention when setting the objectives of a proposed irrigation project, in designing the system and in establishing operational procedures. The two main issues to be considered during the earliest design stage should therefore be: (a) the variability and predictability of flows during the wet season; and (b) the allocation of scarce water in the dry season.

Low Coastal Areas

The southern Chao Phya and adjacent lands in the Bang Pakong and Mae Klong Basins are almost flat and only 1-2 m above mean sea level. These topographic conditions have both positive and adverse effects. They facilitate construction of an extensive system built to serve the dual purpose of navigation and drainage and which are now also used for conservation of water for dry-season irrigation by pumping. Because of lack of slope, fewer structures are required to control water flows than in gravity irrigation projects. Conversely, a large part of the lowest lying lands in these areas is affected by floods during the wet season because of insufficient drainage. Aggravating this situation is the effect of tides which reach a maximum amplitude of 2-3 m in the Gulf of Thailand. During high tide, water can be diverted without pumping when quality is suitable for irrigation, although sea
protection dikes are required to prevent submersion of low areas along the shore. During the dry season, sea water intrusion can affect the quality of water up to 40 or even 60 km from the sea, not permitting diversion for several weeks.

C. Canal System Design

3.09 Until the early 1970s, canal systems were primarily used for supplemental wet-season irrigation and they generally achieved this objective. More recently, RID designs were patterned on the design standards of the U.S. Bureau of Reclamation, but were less comprehensive. The RID designs are acceptable in a situation of abundant water during the wet season, but pose several operational problems for dry season irrigation.

3.10 Canal Size. Until the early 1970s the main and lateral canal systems were designed for peak demand during the wet season. The design capacity in the Northern Chao Phya was 0.13 liter/s per rai (0.81 liter/s/ha) for the canals and 0.14 liter/s per rai (0.91 liter/s/ha) for the structures. This is only about half the capacity needed to accommodate the 0.24 liter/s per rai (1.4 liter/s/ha) required to achieve a 100% cropping intensity for paddy during the dry season. The present transit capacities thus constrain the allocation of dry season water. Without remodeling part of the main and lateral systems, it would not be possible to supply enough water for dry season irrigation of paddy over the planted area (assuming use of an annual rotation method which provides water for one dry season out of two or three, on half or one third of the total project area, paras. 6.03-6.05). The most recent projects have been designed to avoid this problem, and capacities have been calculated on the basis of the average dry season cropping pattern. A margin of additional capacity is even provided to allow flexibility in the choice of cropping patterns. In the Mae Klong Project the design capacity of about 1.7 liter/s/ha is adequate for cultivation of rice and sugarcane on 80% of the project area.

3.11 Operation at Full Capacity. Until recently the canal systems including the tertiary systems were designed to be operated only at or near full capacity with a minimum of control structures. The result is that at flows below the design capacity, water levels in the canals may not be high enough to ensure command of the entire service area and to provide full supply to the subsequent order canals. In principle, the solution is to build additional control structures to ensure a minimum water level at the diversion points independent of the flow in the parent canal.

3.12 Type of Control Structures. Operational staff are needed to control the water levels and flows of all structures built in the irrigation canal system. With the exception of some main regulators in the northern Chao Phya area which are electrically controlled, all structures are manually operated and any significant variation in supply or demand of water in the system requires readjustment. Almost no form of automation has been built into the
design of these structures. The maneuverability of gates equipping head and cross regulators is in some cases limited and any change in their setting is time consuming. The determination of flows through each structure requires calibration of the gates and frequent measurement of water levels in the absence of automation. In recent years, RID has initiated a program of gate calibration.

3.13 The last water distribution control point is the farm turnout delivering water to service areas averaging 30 to 60 ha. Until the late 1960s, farm turnouts were equipped only with simple gates. This prevented any flow measurement, which was in any case unnecessary at that time because the systems were intended for wet season irrigation only. Constant head orifice (CHO) gates and movable weirs (Rominj type) were introduced in the late 1960s and 1982, respectively, to control and measure flows through the farm turnouts. These two devices, especially the movable weirs, are sensitive to variations in the upstream water level and therefore require frequent adjustments to maintain constant flow deliveries to the service units. Both devices are designed to measure the flows at a given time but are not self-flow-controlling. An additional disadvantage to the CHO gate is its relative complexity of operation and need for frequent readjustment with the result that CHO gates are rarely used properly. The Rominj weir has so far been introduced only in the Mae Klong Project. Although simpler to operate, its use is limited to canal sections with strict control of water levels.

3.14 In addition, unclear operational manuals offering excessive information and unnecessarily complex procedures for the operation of simply designed control equipment are an obstacle to the training and subsequent motivation of operations staff.

3.15 Conclusion. Operation of existing control structures, either the main regulators or farm turnouts, is an unwieldy task. Day-to-day regulation of water levels and flows in the distribution network involves frequent routine setting of all gates because of the instability of hydraulic conditions in the systems. RID has been successful in organizing routine operations of the head and main cross regulators in the Chao Phya project, but less so in operating main structures in other projects. As for minor canals and farm service areas, no water control has been organized except for a few pilot-scale projects. This failure is related to the cumbersome operation of a number of farm turnouts and even more to the unreliability of existing devices. These factors often cause farmers to interfere in farm turnout operations and ultimately to remove the gates. The Samchook project (50,000 ha) in Chao Phya, for example, includes 30 main structures which are controlled

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4/ There are at least three exceptions: the Mae Tang, Nong Wai and Phitsanulok canals are equipped with weirs permitting automatic control - within certain limits - of the water levels. It should be pointed out that automation in irrigation projects does not necessarily imply sophisticated, computerized devices; the Nong Wai system, for instance, is equipped with simple hydraulic structures, such as bypass weirs, which serve the purpose.
and reset at appropriate intervals, but 230 farm turnouts which are virtually uncontrolled. Introduction of the simple, reliable and self-controlling devices discussed in Chapter 5 of this report (para. 5.23) would be of great assistance in improving system performance.

D. Drainage Systems

3.16 Flooding or the probability of flooding is one of the main factors influencing current rice cultivation practices and is the major bottleneck hindering further improvement in these practices. Conditions are not favorable to proper drainage of some irrigated areas in Thailand, especially in flat and coastal areas. But even in other areas the drainage system has some drawbacks. This is the case in the northern Chao Phya. First, to speed up the program of drain construction a decade ago, the drains were excavated at half their design capacities. Second, the drainage system is not independent of the irrigation system. The main drains on the west bank of the system flow into the man-made or natural irrigation canals. Therefore, during flood seasons, drainage capacity is reduced by the back-water effect from the canal system. In these areas farmers take advantage of this situation to grow floating rice, but by damming the drains to maintain the required water depth they contribute to the drainage problem. A drainage and flood control improvement program in northern Chao Phya, consisting of connecting some drains together and disconnecting them from the irrigation system, was recently proposed, but this solution may aggravate flooding downstream. The problem of drainage and flooding in the greater Chao Phya including the metropolitan area of Bangkok has to be studied in its entirety before embarking on local solutions such as the one above or the polderization of large areas in the southern Chao Phya.

E. Incomplete Systems

3.17 Many irrigation systems are incomplete and cannot operate efficiently for that reason. They are incomplete either because their designs made no provision for on-farm works and tertiary systems, or because conveyance and distribution systems were never finished, presumably due to insufficient budgetary allocations. Although large-scale projects have included construction of on-farm works and tertiary systems during the last decade, this is not true of medium- and small-scale projects, which to one extent or another often lack these systems. The O&M Division is currently confronted with a considerable need to construct complementary works in operating systems, for which it has insufficient budget and manpower.

F. Inadequate Maintenance

3.18 No irrigation project can function up to its design potential without regular maintenance, and poor upkeep of irrigation facilities ultimately necessitates extensive and costly rehabilitation. This is frequently the case in some regions of Thailand where operational problems created by the design of the irrigation and drainage systems are compounded by inadequate maintenance. Most severe maintenance problems are observed in the Northeast where siltation and failure of canal linings due to sandy soils are common. Problems include: (a) the failure of the concrete side panels of canal linings;
(b) sedimentation in projects where no precautions have been taken to prevent sediment from entering irrigation canals; (c) aquatic infestation, especially floating hyacinths in the Chao Phya area; (d) minor control structures which have been removed by farmers, damaged or only partially installed; and (e) in some areas, extensive use of the irrigation system for fishing. It is believed that the reason farmers damage irrigation structures is their lack of confidence in systems which cannot deliver water in a timely and equitable manner. In general, medium- and small-scale projects receive little or no maintenance. As a result of insufficient routine maintenance in the past, RID is now confronted with a tremendous backlog of maintenance work, but insufficient equipment, manpower and budget to carry this out.

3.19 Newly developed projects like Phitsanulok and Lam Pao are also affected by insufficient maintenance since no formal arrangement has yet been made for operation and maintenance of completed sections of these projects. Creation of new permanent staff positions for operation and maintenance after completion of construction takes a rather long time, during which RID has to manage with temporary and construction staff. Procurement of vehicles and maintenance equipment is also a lengthy process. The immediate need for maintenance of recently developed projects is exacerbated by the absence of formal procedures for transferring responsibility for completed facilities from the Construction Division to the Operation and Maintenance Division. It would be a good practice during the first two to three years after completion of works by contractor or force account for the Construction Division to retain responsibility for carrying out any corrective measures and complementary works which may be needed during the initial period of operation. The lack of corrective measures only contributes to rapid system deterioration.

3.20 To some extent, system deterioration may in the past have resulted from adverse field conditions during construction, for example, compaction of earthfill and placing of concrete linings during the rainy season. The practice of borrowing fill material within the right-of-way of canals is now discouraged by RID design engineers.

3.21 The combination of all these factors places an upper limit on the level of performance which management and operational staff are able to achieve. The findings of the Irrigation Program Review in 1976 are still generally valid: "Water control within most irrigation projects leaves a lot to be desired." With the exception of the main system, there is little or no control on water flows. In general, the distribution system controls neither the timing nor the amount of water delivered and the on-farm water management practices are wasteful of water.
4. PERFORMANCE OF EXISTING PROJECTS

4.01 The performance of irrigation projects can be measured in terms of production economics or water use. This study focuses on the latter. The only measurable criteria for water distribution are productivity (i.e., tons or value of output per cubic meter) and efficiencies of water use, which are closely linked for upland crops but not necessarily in paddy irrigation. According to these standards, the performance of irrigation systems in Thailand varies considerably; water is excessive at some times and places and inadequate at others. The efficiency is obviously higher during the dry season than in the wet season when the supply is more abundant.

4.02 The quality of water services, particularly the timeliness of water delivery, is less frequently examined, although it is as important to the farmers and to the crops as the quantity of water delivered. The factors playing a significant role in the quality of water management include: (a) the completeness of the project and adequacy of maintenance; (b) the size of project; (c) the topography and nature of soils; (d) farmer organization; (e) water resources and their degree of regulation; (f) the degree of access of farmers to water by gravity or pumping; and (g) adequacy of the operation plan and its implementation. The following discussion illustrates the diversity of project conditions and performance in Thailand.

Greater Chao Phya

4.03 Basin-scale Water Resource Management. The greater Chao Phya is by far the largest irrigation project in Thailand, and RID has given special attention to its management. The Chao Phya Basin covers an area of 180,000 sq km or 35% of the country and includes about 50% of the irrigable lands. About 50% of this flow is uncontrolled. The operational concept, simple in theory, is to make full use of uncontrolled flows as well as rainfall over the irrigated areas before drawing water from the two main reservoirs, Bhumiphol and Sirikit. The transmission time from these reservoirs to the diversion dam, 300 km downstream, is about five days. Management of water resources in the Chao Phya Basin is quite complex because of the importance of uncontrolled flow and the erratic nature of rainfall over the Basin. Reservoir releases and diversion into irrigation canals are not easy to adjust to take advantage of rainfall over irrigable areas. Operational improvements are needed to ameliorate this situation, at least in the periods when rainfall is most uncertain. More substantial improvement in the system is constrained by the lack of active storage capacities in the reservoir created by the Chainat Dam.

Efficiency of any component of an irrigation system (conveyance, distribution or farm ditch) is the ratio of the volumes of water flowing "out" and flowing "in"; farm efficiency is the quantity of water placed in the root zone (rainfall deficit) and the total quantity under the farmer's control.
4.04 Management of the Chao Phya system is further complicated by the fact that irrigation is competing for the limited Chao Phya water resources with other needs like energy generation, municipal and industrial water supply, water quality and sea water intrusion control, and navigation. By the mid-1970s it became evident that the potential demand for this water far exceeded the supply. Rising prices for rice and the availability of new varieties led to a surge in dry season cropping. At that time the installed generating capacity of the Bhumipol and Sirikit Dams represented 93% of the total hydroelectric capacity of the country. An updated basin study was therefore needed to guide use of the Chao Phya system, and RID, EGAT and a consulting firm worked together on the necessary analysis. The recommendations of the study emphasized operational improvements as an inexpensive and rapid means of obtaining substantial agricultural and energy production benefits. The study also formulated recommendations on the prudent development of new projects in the basin, encouraged further diversion of water from the Mae Klong to the Chao Phya Basin, and offered specific recommendations on operating policies.

4.05 The main follow-up of that study has been the development and implementation of a computerized Water Management System (WMS) to coordinate water allocations in the Chao Phya Basin. The water management system (a) assesses actual irrigation water requirements based on crop conditions and rainfall data, (b) establishes reservoir releases, taking into account uncontrolled sideflows which can be expected below the dams and interaction between all water users, and (c) guides weekly allocation of water to each of about 80 main regulators. The system simulation model accounts for conveyance and other losses and for return flows. The WMS is used by the RID staff of the Water Operation Center (WOC) which is fully familiar with it and its application. Significant improvements in irrigation efficiencies in the Chao Phya project and reductions in the rate of use of reservoir releases for dry-season irrigation have been observed. The Chao Phya flow diverted for agricultural purposes during the five-month period January to May has decreased from about 16,000 cu m/ha in 1976 to 7,200 cu m/ha in 1982.

4.06 The WMS has some inherent limitations. The system is patterned on the mathematical model used in operation simulation studies of reservoirs which are generally run on a monthly basis; the WMS, however, was intended to be run on a weekly basis. In practice it is run about once a month, possibly because of the time required to collect and compile all the information needed for the model and because of obsolete computer facilities. There is also an interval of at least two weeks between the time of data collection and the transmission and execution of orders at the main regulators. A review of the flows calculated by the model and the actual flow conditions show little or no relation. In practice, the WOC makes its own projections of water allocations among irrigation projects based on actual conditions and experience. These projections are transmitted to regional headquarters and project offices day-

6/ These figures do not represent the irrigation requirements for the dry-season crop but are only the diverted flow during the five months when uncontrolled flows are the lowest.
to-day or at necessary intervals. However, this does not diminish the success of the WMS in managing water resources at the basin level. It is a remarkable tool for the allocation of water among users and irrigation projects and for the calculation of water releases from the reservoirs. Nevertheless, experience has shown that the WMS is of little help in the day-to-day operation of a canal system.7

4.07 Main Canal System. For management purposes, the greater Chao Phya project is subdivided into 26 irrigation projects, half in the northern gravity systems and half in the southern water conservation systems. Project officers report to one of two RID regional offices: one for the east bank of the Chao Phya and the other for the west bank. The greater Chao Phya is served through five major canals including the Suphan and Noi River channels diverting water from the Chainat Dam reservoir. Each project office is responsible for water distribution in the areas served by a certain number of laterals and for operation of the main canal sections crossing their areas. Each project is therefore dependent on the water releases and performance of the upstream projects.

4.08 RID has succeeded in establishing operating procedures for the main canal system in Chao Phya and in coordinating water management by the WOC as well as the regional and project offices. The latter have demonstrated their capacity to operate the main system according to fixed rules. Water levels and gate openings are checked at regular intervals of 4, 6 or even 24 times a day depending on the importance of the regulators. The gates are reset when necessary to meet water level and flow targets. Performance levels for operation of the main canals are close to the upper limits attainable with the present control and communication infrastructure. Water levels in main canals are remarkably steady. One noticeable problem in main system operations occurs at the Chainat Dam during low flows (with a maximum pond level of 16.0 m), which limit the flows diverted into the Chainat-Pasak main canal to below its maximum capacity.8

7/ An example of a water management system which does regulate canal operations is the centrally controlled Muda project (97,000 ha) in Malaysia. Information on crop conditions and rainfall are transmitted twice a day to a central control room. Computerized real-time models are run three times a day to calculate water diversion, reservoir releases, and gate settings of the 16 major structures, with the results transmitted by radio to the field. The project's advanced management and technology permit a maximum use of rainfall over the irrigated area and of unregulated flows between the reservoir and diversion structure.

8/ To maintain the dam's structural stability, the permissible head is limited to 9.0 meters. This limits the maximum pond level acceptable during low flow releases into the Chao Phya River to meet minimum water requirements for navigation, water supply, etc. This in turn limits the flow which can be diverted into the Chainat-Pasak canal to below maximum capacity since the intake is a type of gated orifice rather than the more common sluice gate.
4.09 **Lateral and Tertiary Systems.** Water use conditions at the lateral and farm levels in the northern gravity systems and the southern water conservation systems are completely different and should be examined separately. The subject is well documented by a series of reports prepared by RID and a consulting firm on water uses in four typical projects. Problems in the gravity projects in the northern area are generally related to overuse of water and difficulties in maintaining gravity command. In the water conservation projects, problems are generally related to inadequate security of supplies and imbalances between available supplies and dry-season crop demands.

4.10 **Operational Practices in Northern Chao Phya.** The operation of lateral canals in gravity areas is complicated by the huge number of farm turnouts to be controlled and the inherent operational deficiencies of these devices. The project offices attempt with variable success to operate the lateral canals controlling water levels and flows at head regulators. There is practically no control of water deliveries at farm turnouts except to reduce the risk of flooding. In practice, control is impossible since most of the gates have been removed or damaged. In addition, a significant number of farm turnouts have been installed by the farmers themselves and are uncontrollable. Actual water distribution allows a continuous flow through the farm turnouts.

4.11 Detailed analysis of water use practices in two projects show the following deficiencies in distributing water to service areas:

(a) Water supply is not patterned on crop demands. Theoretical requirements and actual supply show little relationship below lateral control. Thus, supply is not planned in advance according to requirements;

(b) Rainfall is not utilized beneficially and water deliveries are not adjusted to reflect actual rainfall. Adjustments are made in some areas at the request of farmers to prevent risk of flooding when rainfall amounts are largest;

(c) Although efficiency seems high at critical times of maximum demand, this only reflects the fact that in many zones demand exceeds supply, in part because farmers often plant more than the official dry-season area which is determined on the basis of the actual reservoir storage at the end of the rainy season. RID lacks sufficient authority to prevent overcropping during the dry season, and once the crop is planted, RID normally attempts to supply the full cropped area;

(d) The supply of water is very inequitable. Areas close to the head regulators typically receive an excess of water for most of the season, whereas areas at the end of the delivery system experience chronic shortages; and

(e) Supply of water is unreliable. A flow at the turnout can fluctuate randomly from less than 50% of the theoretical requirement to more than twice this amount, nullifying any effort to organize water
distribution at the farmer's level. Fluctuations of water levels in the laterals combined with the sensitivity of farm turnouts to these variations cause the irregular supply rates.

4.12 Due to the present low level of water distribution, there is little or no cooperation between RID officials and farmers, and farmers typically do not cooperate among themselves. They normally try to protect themselves against the unreliable supply by hoarding water. Repair or reinstallation of the existing type of farm turnouts would again lead to damaged structures. Cooperation and understanding between farmers and RID and among farmers cannot be established until water is delivered to farmers in a timely and reliable manner from the main system.

4.13 Operational Practices in Southern Chao Phya. The multipurpose channel networks in the conservation project of southern Chao Phya provide irrigation, drainage, fisheries and navigation benefits. Control structures are restricted to head regulators which control flows diverted from the main rivers in terms of quantity and quality, and regulators to control diversion of flows between branches and drainage regulators. Virtually all farmers have to pump irrigation water from the canals into their fields during the low flow period. The most common pumps are still the traditional chain bucket type.

4.14 During the rainy season, the entire area is inundated to variable depths. On the west bank where water depth can exceed one meter, farmers have given up the traditional wet season crop and now grow a single dry-season crop. Water stored in the channel system contributes substantially to satisfying water requirements in the early dry season by supplementing water received from projects higher in the system that drain large quantities of water. Shortage periods occur often. This is caused by over-cropping and by insufficient supply to the project areas during the growing season aggravated by the incapacity of the canal system to meet the peak demand. Overall, water management in the southern Chao Phya is constrained by the tidal effect on the drainage capability, sea water intrusion which affects the quality of water during the dry season, and the need to maintain navigation communications.

4.15 Efficiency of Irrigation in Chao Phya. There are considerable variations in irrigation efficiencies in the Chao Phya between the dry and wet seasons and between gravity and conservation projects. There are also variations between efficiencies at the farm level and the individual project level and the overall efficiency of the greater Chao Phya. Efficiencies are lowest during the wet season and have little significance when there is an excess of uncontrolled flows.

4.16 Efficiencies of conservation projects are higher because farmers pump water from the channels at their own expense. The cost of pumping forces them to operate efficiently. Efficiencies at the farm and project level can average 80 to 90% although these high figures may actually reflect inadequate irrigation.

4.17 The northern Chao Phya area close to a main supply source receives an excess of water in most seasons while areas far from the supply are inadequately supplied. Efficiencies can average 40-50% and below in the most
favorably located areas but can be apparently very high in the tail-end areas; this reflects the inadequate supply capacity of the system, the attempts by farmers to spread limited supplies over larger crop areas, and the practice of intercepting water drained from zones higher in the system.

4.18 The overall efficiency of the Greater Chao Phya was assessed by Bank staff at 70-75% during the last few dry seasons. This high level was attained because of the combined nature of the drainage and the irrigation systems permitting a substantial recovery of drained excess water for subsequent reuse. Although water use efficiency in the Chao Phya is high compared to other projects, there is considerable need for improvement to provide water when and where needed.

Projects in the Northeast

4.19 The seven largest reservoirs in the Northeast can provide water to only 190,000 ha of the more than 4 million ha suitable for paddy cultivation in the Region. In contrast to the Chao Phya Basin, the large scale projects in the Northeast benefit greatly from an annual or even interannual regulation of their entire water resource. This applies to the Nam Pong, Lam Pao, Lam Nam Oon, Huai Luang, and Lam Don Noi projects which have a potential for cropping intensities of about 50-70% of the irrigable area during the dry season. Despite this advantage, the performance of most irrigation projects in the Northeast is much lower than in the Central Plain, largely because of the sandy soils and difficult topography. The design and construction methods used in the Central Plain have not been adapted to the specific and more complex conditions of the Northeast and the inappropriate designs exacerbate the deficiencies of the RID standard control structures. Aggravating the combined effect of operational constraints and adverse soil conditions is the poor maintenance of the system which has led to its rapid deterioration.

4.20 Low irrigation efficiencies are observed almost everywhere, even in the most recently constructed or rehabilitated projects. A study conducted in the 1979 dry season to evaluate the performance of the Lam Pao project found an overall project efficiency of 15% which was a combination of conveyance, tertiary distribution, and field efficiencies of 45%, 68% and 51%, respectively. The same study reveals that the difference in seepage losses between lined and unlined canals is in many cases not significant because of losses through cracks and breakages in canal linings. Average water consumption in the Lam Don Noi project supplied by pumping from the adjacent reservoir varied between 23,000 and 30,000 cu m per ha between 1980 and 1983, at least two or three times the cropping demand. Actual dry season cropping intensities are below 15% in most cases and in some years are insignificant.

4.21 Additional factors contributing to the low performance of these projects in terms of agricultural production include the poor soil conditions, the inexperience of farmers in upland crop cultivation, and the lack of field staff trained in irrigation system operations. In contrast to the Chao Phya,

9/ For upland crops and rice.
there is a less systematic approach to determining crop demand and releases from the reservoirs. Throughout the distribution systems, water delivery is not based on crop demand, and there is essentially no management of the system. In the Nam Pong project, which directs water from a diversion dam, the fluctuations at the head regulator when not corrected continue to increase as the water flows down, with the result that the lower portion of the system receives highly fluctuating supplies.

4.22 With bilateral aid and technical assistance from the Asian Development Bank, RID has recently started a program to improve irrigation performance in the Northeast. It was found that substantial emergency maintenance works such as desilting and repair of damaged concrete linings and gates are in many cases necessary before improved operations could be initiated. RID and their consultants recognize the need for managing the main system before directing attention to on-farm water management. In one project, the Lam Nam Oon, RID staff have progressed in achieving their first two objectives: (a) estimating water needs and scheduling changes in water delivery on a weekly basis, and (b) maintaining steady water levels in the main canals. They are still confronted, however, with the complexity of operating a canal under variable conditions such as rotation between laterals, while maintaining constant deliveries to service units. They also recognize that gate setting for a manually operated system is a difficult skill to acquire: "more an art than a science."

4.23 The Nong Wai Pioneer Agriculture Project represents a systematic attempt to upgrade irrigation at the main and tertiary levels, and to introduce farmer water user groups and rotational irrigation. Water level control structures in this project consist of by-pass weirs, a more practical solution than standard check gates. The project has demonstrated that the desired improvements are technically and organizationally feasible under conditions of a single rice crop and somewhat abundant water supply. A more complete discussion of the success of rotational irrigation in this project is presented in para. 6.10.

Medium Scale Projects

4.24 About 70% of existing medium scale projects are located in the Northern and Northeast Regions. Approximately two thirds of these projects are diversion types, the remainder being mostly storage projects (nearly all in the Northeast) and about 3% pump projects. The main limitations to water management are:

(a) The uncertain supply of diversion projects. Natural river flows during the dry season show a tendency to decline from north to south because of variation in rainfall, soils, and topography. The water scarcity prevents farmers from intensifying their dry season cropping, although it encourages crop diversification. The highest cropping intensities (160%) are observed in the Chiang Mai valley where double and even triple cropping is practiced in areas with plentiful water year-round. In other regions, cropping intensities may be very low or even insignificant;
(b) Incomplete projects. A large proportion of the medium scale projects lack distribution systems. Until recently the RID practice was to build reservoirs or diversion structures and the main canals, leaving farmers to build the laterals, farm ditches and drains. In practice there is no management of most medium- and small-scale projects, with the exception of head regulators to avoid overtopping canals;

(c) Inadequate control structures for distribution systems served by unregulated flow. Where the supply is highly variable in diversion projects, the standard control structures geared to human intervention are not adequate. Simpler structures dividing the flow equitably would be more appropriate.

People's Irrigation Projects

4.25 Through experience, farmers in the North have evolved a well-developed and organized irrigation system. They learned to install weirs across natural streams to divert water to their fields through a maze of ditches and dikes. Irrigation Associations are organized to take care of operation and maintenance including repair of the weirs after floods and desilting of canals. The willingness of farmers served by such systems to cooperate for the benefit of their community is extremely strong. Although there are almost no permanent control structures, and even no head regulators in some cases, the farmers make the best use of the supply. Cropping patterns in each community area are closely related to the water supply. Water is distributed on a continual basis and proportionally allocated. Farmers do not hesitate to practice intermittent irrigation of rice and have no tendency to hoard water as in other regions. In case of shortages during the dry season the officers of the Associations define priorities to minimize damage to crops. Since there are usually a number of People's Irrigation Projects along the same stream, the upstream communities benefit most.

Conclusions

4.26 The performance of irrigation projects in Thailand varies considerably from one project to another, depending on a variety of interacting physical and nonphysical factors. There are few similarities between the management of a major project like the greater Chao Phya using partially regulated water and highly trained staff, a medium-scale diversion project, or a People's Irrigation Project developed by a traditional cooperative community in the North. Problems of water management and solutions to these problems are specific to the type of project. However, the initiatives taken by RID during the past decade to improve water management indicate the following:

(a) Improved management of water resources on the basin scale can dramatically increase dry season cropping intensity. This is illustrated by the success of the Water Management System of the Chao Phya project;
(b) Little cooperation among farmers to organize water distribution at the farm level can be expected in newly developed projects as long as the supply of water from the conveyance system is unsuitable and unpredictable;

(c) The basic technology of existing systems was determined by the historic development of water resources and is now imposing severe constraints on improved management. Canals which were designed to run at full capacity for supplemental irrigation lack the necessary structures and capacities for dry season irrigation; and

(d) The reliability and adequacy of water control structures play a major role in the level of water management attainable. The substitution of simple design devices by a large number of trained and motivated operations staff is, in practice, limited to the main systems owing to the limited number of their control points. Attempts to improve water deliveries at the farm level have had limited success and have not been extended beyond the pilot project scale because of substantial operating costs and manpower requirements.

5. MAIN SYSTEM IMPROVEMENT

5.01 Concern for improved water management in Thailand is relatively recent. As long as rice cultivation was limited to the wet season crop, there was little need for more efficient water use, and rice production increased through expansion of the cultivated area. When the vast program of gravity irrigation projects began first in the Chao Phya Basin and then in other regions, emphasis was placed on the design and construction of major structures to store and convey the water, with a tendency to under-rate the importance of distribution facilities. This trend has led to the neglect of water control structures. Furthermore, no clear operational objectives and subsequent operating rules dependent on the characteristics of each project were defined and reflected in the design. As a result of this development:

(a) The same concept of control facilities has been applied to all types of gravity projects in Thailand without sufficient consideration for the variability of the water supply; and

(b) The operation of all control facilities from the water source to the farm level requires almost constant human intervention for high performance. This in turn requires greater management inputs.

5.02 With the increased number of completed projects, the progressive introduction of dry season cropping, and the long-term trend toward crop diversification, RID is now confronted with (a) the need for improved project operations with insufficient skilled staff, budget, transportation and communications; and (b) the need to find new approaches to irrigation operations in future projects. In its response to these needs, RID will have to define water management objectives, concepts and technologies for its future system improvement and new development activities which are appropriate to the set of conditions of each specific project or category of projects.
Definition of Objectives

5.03 First to be defined when planning an irrigation system, whether a new project or improvement of an existing one, are its direct objective(s) which are dependent on a variety of factors such as the variability and predictability of the water supply, climate, crops, etc. There are multiple ways of assessing a system's success.

(a) Productivity of water: If water resources are more limited than land or labor, the productivity of water - measured in terms of agricultural production or efficiency in relation to crop water demand - are now the most commonly used criteria for good water management. Efficiency can be assessed at different levels of the system, ranging from the individual farmer to the whole project. It has less significance, however, in diversion projects where the supply is highly variable and uncontrollable;

(b) Quality of Services: This refers to adequate quantity, timing, controllability, and predictability of the water received by the water users; and

(c) Environmental Impact: This refers to the capacity for long-term irrigation without negative environmental effects such as salinization, water logging and groundwater depletion. To some extent it reflects a project's success in achieving the above objectives.

5.04 Equity and fairness of distribution has been the primary objective of most traditional irrigation projects. With an unreliable and unregulated water source, equity can be achieved by continuously subdividing the available inflow among channels. The physical infrastructure is simple, operating requirements are minimal, and when flow allocation rules have been established, there is little need even for cooperation among neighbors. With a relatively stable water supply, equity can be achieved through fixed rotational irrigation although the rotation rule requires a higher number of control structures and operating staff. While desirable, equity does not guarantee efficiency, since a rigid delivery schedule can create problems of both over- and under-irrigation.

Choice of Technologies

5.05 Following definition of the system's objective(s), a technology should be selected which is appropriate to the conditions under which the system will operate. A wide range of technologies are available for delivering water in different social and physical contexts. They can be applied both in designing new projects and in upgrading existing projects, although the constraints imposed by existing infrastructure may severely limit the choice and applicability of some technologies.

(a) For new projects the question is to select the most suitable technology based on physical and non-physical factors such as crops, soils, topography, rainfall pattern, farmers' tradition of irrigation, technical level of system operators, etc. The difference in
investments between technologies may be offset by the amount of
management needed, and the consequence of this on operation and
maintenance costs may be substantial.

(b) For existing projects, the choice in improving their performance may
be either substantial investments in infrastructure to upgrade and
correct the system, or better management requiring higher budgetary
allocations and training - or a mix of both. This is the situation
that RID now faces. The approach so far has focused on improved
management together with rehabilitation, although with mixed
success.

5.06 The various technologies can accommodate a range of physical
factors, such as the nature of the water supply, although with varied success
with regard to productivity, quality, equity, etc., and major differences in
requirements for operation and maintenance. However, even before selecting a
particular technology and designing the project, the system’s operating rules
should be determined, since the eventual performance of the system will depend
on how well the design promotes its operation. Definition of the operating
rules should therefore precede design of the physical infrastructure. In
determining the future operations, a number of factors must be considered, the
most critical one being the variability of the water supply, i.e., run-of-the-
river, storage, or groundwater. These decisions are crucial and not easily
reversible in the later stages of detailed preparation.

5.07 The following overview is limited to the various technological
options available to achieve efficient, timely, reliable and equitable water
distribution, having no ill-effects on the environment. The simple but effec-
tive structures used for fair water distribution in traditional irrigation
projects are therefore not discussed in this paper.

Technologies Available for Canal Control

5.08 Canal control can often be improved with the use of simple, indepen-
dent, local automation techniques providing either upstream or downstream
control. Alternatively, a system can be operated using remote control. Any
decision on which alternative is most appropriate should be made only after
weighing the advantages and disadvantages of each system.

5.09 With upstream control, water is released at the head regulator and
delivered to turnouts or lateral canals according to a prearranged schedule.
For centuries upstream control was the only technologically feasible method.
Upstream control utilizes cross regulators or check structures in the supply
canal for the purpose of maintaining a constant water level in the supply
canal upstream of the offtakes, regardless of the flow rate in the supply
canal.

5.10 Upstream control can be achieved by conventional gated structures,
as is presently the case in Chao Phya. However, many small gate adjustments
are necessary because the flow rate changes arrive gradually at the various
regulators along the canal. Indeed any change in the operation of a canal
system requires a certain time lag, and settings are bound to be inaccurate
because control operations often are executed before a new hydraulic regimen has stabilized. In summary, precise predictions of gate adjustment times are difficult due to the large number of hydraulic variables and the complexity of properly evaluating them in the field.

5.11 A simple weir designed with a long crest of the duck bill type can achieve a nearly constant upstream level, and without human intervention. This is a considerable advantage over the manually operated flashboard or simple gated structures. An ingenious alternative is the hinged type overflow motorized gates used in the Muda project in Malaysia which can be easily adjusted.

5.12 Alternatively, existing sluice and radial gates can be easily automated with a local, independent controller for upstream control. A controller has been developed in the United States for this automation. It was originally designed as an electro-mechanical device, but has been replaced with a microprocessor and pressure transducer in some installations. Radial gates have the advantage over sluice gates of requiring less energy for movement.

5.13 Other possibilities include the constant upstream level gates developed in France which require no electricity and have only one moving part. These gates work on a principle of balancing forces, with a large float positioned on the controlled water surface. The upward force of the float is balanced by downward forces of two ballast containers. The ballast must be precisely adjusted during installation for stable operation. These hydraulically operated gates typically have the outstanding advantages of requiring no electricity and being quite robust and highly reliable. Although more expensive than conventional gates, they require minimal maintenance.

5.14 The methods described above can be used to automatically provide constant water levels upstream of the regulators. Nevertheless, the canal must still be controlled from the upstream end with a prearranged schedule of deliveries. Uncertainties of transit time of water in the canal and water demand cause some inevitable water wastage. Downstream control does not have these limitations.

5.15 In a downstream controlled canal, the flow through it is controlled by the users - or the offtakes' operators - along the canal. Gates designed to maintain a constant level immediately downstream and regularly spaced along the entire length of the canal ensure a step-by-step transmission of the

10/ In a non-automated system, overflow type check structures have clear advantages over underflow gates: (a) the flow across the structures is not affected by downstream conditions; and (b) the upstream water level is less sensitive to flow variations (doubling of flow rate over a weir results in a 60% increase above the weir whereas with underflow gates the water level difference is increased by four times). In spite of the hydraulic advantages of overflow structures, they are not frequently found in irrigation canals.
demand. An increased flow requirement out of a pool causes the water level to drop in that pool. The gate upstream of the pool opens slightly to maintain a constant level. This process is automatically repeated in each upstream pool up to the head regulator. With downstream control, not only is the water level controlled but the flow adjusts automatically to the demand.

5.16 The hardware for downstream control is similar to that used for upstream control. Either an hydraulically operated gate can be used or an electrically assisted controller with the sensor placed downstream of the gate rather than upstream. Cylindrical valves acting as a balance float valve can operate under low pressure.

5.17 A great advantage of this operational system is that turnouts taking off from a downstream-controlled canal can be reset at any time without causing problems. Even better, downstream-controlled systems make the life of canal operators much easier by drastically cutting down on the amount of information transfer required and the need to constantly juggle a system to minimize tail-ender and wastage problems. Communications between operation staff and computational requirements for safe and flexible operation of the system are thus minimized.

5.18 Pure downstream control as described above, does, however, have the disadvantage of requiring the raising of the berms of the canals to accommodate the water profile at zero flow. The system therefore has some economic limitations relative to the slope of the canal, which is usually less than 0.30 meters per kilometer. In addition the development of housing, roads, etc. along existing canals may be a serious obstacle to the adoption of this alternative. But some solutions have been developed to avoid the limited application of this system to low slope canals and to shorten its response time. For example, electrically operated downstream-controlled systems like the EL-FLO and BIVAL systems also called "remote localized control" have been successfully developed in the United States and Europe to respond to water level changes anywhere in a pool. The BIVAL type is a constant volume flow control system which minimizes the diking works. Under certain circumstances, such as in the Sahel canal of the "Office du Niger" in Mali, automation can even be deferred and manual gate control can be continued with new procedures. However, the stability of these remote localized methods has to be checked with a mathematical model, especially when the water level sensor is far from the controlled regulator.

5.19 Conclusion. Most of the systems described here have worked successfully for many years and some of them even for decades. Long crest weirs have been commonly used in Mediterranean countries since the 1950s. Automatic upstream and/or downstream control systems were first tested in Algeria shortly before the Second World War and their use spread throughout North Africa, the Middle East and other Mediterranean countries. They have now been introduced in nearly 20 countries including a few installations in Japan and Malaysia. When combined with proper canal management, these systems have helped to provide the ultimate users - the farmers - with a manageable and dependable supply of water.
5.20 Centralized Control. Individual gates of a system under localized control or remote localized control are operated serially as the hydraulic head increases or decreases along a canal. With remote control, all the regulating facilities including pumping plants, if any, can be operated simultaneously or nearly so, and the requested changes in flow conditions can be made immediately. Remote control systems perform the following four basic functions in the operations of an irrigation system:

(a) Data acquisition and monitoring (crop and climatic data, and monitoring of control facilities);

(b) Data communication and transmission to a central control center;

(c) Data processing; and

(d) Operation of water control facilities.

5.21 A wide range of remote control systems are possible, from the simple one with voice communication to the most sophisticated one which is entirely computerized. Data acquisition can be obtained through staff readings or automatically by use of appropriate transducers which transform sensed data into appropriate signals for transmission. Transmission of data can be accomplished by telephone lines, cables, radio (VHF), microwave or satellite, or by a combination of such systems. All the control points can be constantly monitored and/or visually displayed. In the simple case, a central operator decides on the adjustment required. For careful water management of a large and complex irrigation project, rapid processing of the voluminous incoming data on a timely basis is required. In this case the information processing and the complex calculation of the required adjustment has to be accomplished by use of an industrial computer. Changes in setting of the control structures can be manually or electrically operated. Orders from the control center for new settings can be transmitted by operator control through any of the above systems (open loop) or by computer-actuated control (closed loop). The degree of sophistication of remote control can be progressively increased, and the canal system under this control can also be progressively expanded.

5.22 Only a few centralized systems exist in the world. In the United States there are the Salt River, the Coachella Valley, the Californian Aqueduct projects, and few others; in France, the Canal de Provence; in Greece, the Mornos Canal for the water supply of Athens; in Iraq, the Kirkuk project; and in Malaysia, the Muda project. Operation of these systems, which include several storage reservoirs, hydroelectrical and/or pumping facilities, is highly complex. Benefits derived from the centralized automation are an appreciable amount of water savings and the optimal use of storage and energy-related facilities. Progressive introduction of centralized control is now considered in some countries for the operation of complex irrigation systems such as the Haouz canal in Morocco, the Nile in Egypt and the future Narmada project in India, each of the latter projects serving more than 2 million ha.
Technologies Available for Flow Control

5.23 An essential but often neglected aspect of operating irrigation projects is the need to maintain a nearly constant flow at some delivery points in a system. Unless the delivery point is close to a structure maintaining a constant upstream or downstream level (or the canal is run only at full capacity or shut), there are some fluctuations of water level in the supply canal. The most common solution is to equip a simple gate with a measuring device, but experience shows that this is generally inappropriate because of the frequent adjustments required to compensate for variations in the water level upstream and the number of delivery points. The only manageable solution is to equip the headworks structure with a flow controlling device. Two types are available:

(a) An electrically assisted controller actuating the gate to maintain a target water level over a flow calibration weir; or

(b) The distributors (or modules) developed in France consisting of a sill associated with one or two baffles which is designed to deliver a constant flow within certain limits in the water level of the supply canal. These modules require no energy source and are strong and reliable. They need no flow measurement, only opening the right combination of modules corresponding to the target flow. This equipment is now used in nearly 20 countries in association with automatic upstream or downstream water level control structures.

Application to Irrigation Projects in Thailand

5.24 No one technology is appropriate to all the various irrigation projects in Thailand. Most regulation systems discussed above have their specific field of application and could be introduced in the Thai system in the short- or longer-term. For run-of-river projects with somewhat unpredictable water supply, upstream control is generally the only suitable concept. Since most of these projects are of medium- or small-scale and located in remote areas, routine operation should be as simple as possible. Water level control could be achieved through simple structures such as long crest weirs, associated or not with gates. Where topography permits, flow dividing structures should be used to apportion supply between subprojects according to a pre-established ratio. For new projects with reliable water supply, downstream control is the recommended method for the main canals, provided that the topography permits a gentle slope alignment for the canal. Regarding the modernization of projects, the existing facilities may impose some technical or financial limitations to the application of downstream control. The main canals at both the Phitsanulok and Mae Klong projects, for example, were designed for upstream control, rather than the more easily operated downstream control. Selection of a modernization method for these projects, either through conversion to downstream control including additional civil works or a centralized control achieving the same efficiency, would now require an in-depth study of these systems. Improvement of water distribution in the Chao Phya project, perhaps the most challenging modernization project in Thailand, was the subject of a recent identification study by FAO. Operation of the main system could be improved through a centralized monitoring system which
would be progressively expanded. Lateral canals could be improved through the remote localized method (constant volume). In all projects, use of flow controlling devices would considerably improve the reliability and simplicity of water supply at canal and farm turnout offtakes.

5.25 The RID is aware of these concepts and technologies for improving water distribution. Although understandably concerned about the applicability of some of these methods in the social and physical context of Thailand, RID is considering testing some of these methods on a modest scale. For example, part of the Nam Rit project (5,000 ha) would be rehabilitated and upgraded using downstream control for the main canal. This method would present a particular advantage for this project, since savings on pumping costs would derive from the increase in water efficiency. RID should be encouraged to implement similar projects as soon as possible to assess the potential benefits of modern regulation methods on water management and operational staff requirements.

6. THE TERTIARY SYSTEM AND ON-FARM DEVELOPMENT

6.01 Thailand's recent experience with on-farm irrigation development began with the Ditches and Dikes Program during the same period that the first large-scale reservoirs were built. Started in 1961, this program resulted in the construction of outlets and a network of main field ditches at densities of about 25 m/ha (ditch spacing at about 400 m) on one million ha in the Central Plain, and another 250,000 ha elsewhere in the country. The program is still continuing in some areas.

6.02 Construction of ditches and dikes is now widely believed to be a necessary but insufficient condition for the productive use of dry season water. Therefore, since the mid-1970s Thailand has promoted the concept of rotational water use for rice, and has implemented comprehensive land consolidation comprising reorientation of farm boundaries, intensive and rational networks of on-farm ditches, and land leveling. This chapter reviews Thailand's experience with these two innovations, neither of which has greatly improved the delivery of water to the farm. More recently, consideration has been given to other aspects of on-farm operations and design such as annual rotation, farmers' organizations, and size of the service area. While all of these are important and deserve attention in future planning, a pre-condition for efficient on-farm irrigation is the provision of a constant, predictable and adequate flow at the farm turnout.

Rotational Irrigation

6.03 Rotational irrigation is understood in Thailand as the sequential delivery of water from a farm turnout (FTO) to successive parts of the FTO's service area. The rotation is controlled by diverting water into different field channels, which results in discontinuous or intermittent supply to all farms within the service area.
Benefits sometimes attributed to rotational irrigation are:
(a) reduced loss of fertilizers because they can be applied during periods of interrupted supply; (b) equal or higher yields; (c) savings in water use; and (d) faster land preparation. However, experience gained in several pilot projects in Thailand where rotational irrigation has been introduced, and in the Philippines under conditions somewhat similar to those of the Central Plain, has not been encouraging, and has not confirmed the expected benefits:

(a) Carefully controlled studies show that farmers manage on-farm water distribution, even under continuous irrigation, in ways that avoid significant fertilizer losses through surface drainage;

(b) Higher yields in rotationally irrigated plots have been found in temperate countries, but repeated attempts to get the same results in the humid tropics have resulted in insignificant yield differences;

(c) Prospects for water savings through rotational irrigation are limited unless the rotational period is so long as to induce moisture stress, or unless losses due to seepage and percolation (S&P) are very high. The major savings\textsuperscript{11} to be expected from rotational irrigation is a fraction of the water lost to S&P which is very little under irrigated Thai conditions. At most, potential S&P losses may be halved by rotation, but this represents less than 5% of the water supplied at the FTO. Unless there are effective structures and procedures to hold this potential saving within the main system, even this much will not be saved;

(d) Experience has not shown that farmers prepare their fields any faster under rotational irrigation. In general, farmers seek a continuous supply of water before beginning to plow; any interruption, including an intermittent supply schedule, tends to prolong the process. In practice, it has been very difficult to implement formal rotations in paddy irrigation, and almost impossible during the land preparation period. The most effective method during land preparation is sequential supply, in which water passes to further farmers when those near the field channels receive enough to begin tillage; and

(e) The potential for saving water during periods of rainfall is no different for rotational or continuous irrigation, and is determined almost entirely by regulated control in the main system.

The strong reluctance of farmers to practice rotational irrigation at the tertiary level can be attributed to:

\textsuperscript{11} Operational losses from the on-farm network may also be reduced with rotational irrigation. However, almost all these leakages flow into farm holdings and therefore should not be considered as losses.
(a) Variability in FTO discharge. Studies of tertiaries in Thailand show wide variation in FTO discharge rates both over time and across locations. There is little purpose in rotation if water supply exceeds crop requirements by about 30%. Conversely, the discipline required for implementing rotational irrigation breaks down when the water deficit exceeds 25%. Supply in the main system results in relative water supply values at the FTOs which are outside this range most of the time.

(b) Inadequate or poorly designed tertiary systems. The design and construction of functional tertiary systems require more detailed topographic data than those used in building the main system. At present, designs for field channels are often not suitable and act as disincentives by obstructing natural irrigation or drainage ways; they are also often not built to grade. Sound field channel layout for rotational irrigation may require some input from farmers, which has not yet evolved. The continuous form of irrigation which uses simple field channel networks and on-farm structures avoids most of these problems.12

In short, the benefits to induce farmers to help build, pay for, or operate a tertiary-level rotational irrigation network are currently insufficient.

6.06 Lessons from Rotational Irrigation In Taiwan. Studies of rotational irrigation in Taiwan have noted that the program was introduced in the 1950s in association with five related improvements: (a) development of a detailed operations plan; (b) extension training for farmers; (c) installation of measuring and control structures; (d) improvement of the delivery system; and (e) augmentation of the water source, primarily by installing pumping units. With the exception of extension training, all these changes were related to the provision of a more stable and predictable target rate of supply through the FTOs. These improvements have yet to be made in Thailand.

6.07 Experience in Taiwan also indicates that competition for water becomes too intense for successful rotation when the water deficit exceeds 25%. This is the reason for including groundwater augmentation in the program, despite its high cost.

6.08 Rotational irrigation in Taiwan was imposed on reluctant farmers by a combination of the improvements noted above and strong political and financial commitments by the Government. The program was not popular because it resulted in reduced, but generally adequate, supply to many influential farmers. Enforcement of the program required the presence of military and police units in the fields.

12/ In Malaysia's Muda project, the field offtakes to regulate flow from a tertiary canal into the padi field consist of flap gates with two openings at the pipe inlets; the larger opening is used to meet presaturation flow requirements delivered to farmer-groups by turn, and the smaller one for continuous irrigation during the growing stage.
It is clear from the experience of both Taiwan and Thailand that the preconditions for successful rotational irrigation are more important than the rotation itself. Major increases in rice production and water use efficiency have been achieved without rotational irrigation where the systems supply all FTOs scheduled to receive water with flows marginally greater than the water requirements of their service areas. Farmers will then devote their full attention to crop production, and will use the water with greater care.

The Nong Wai Pioneer Agriculture Development Project in Northeast Thailand has adopted many of these principles. It has attempted to supply water through the FTOs at more precisely controlled rates, and to organize farmers into groups of 8 to 12 within units of about 10 ha each. Water is supplied simultaneously to all farmers in a group during one fixed period of about 24 hours each week. The rotational program is carried out during crop growth in the dry season and during limited periods when water is in relatively short supply in the wet season. It is not carried out at other times or during land preparation. Experience so far at Nong Wai confirms the importance of the preconditions for successful rotational irrigation in Thailand, and shows that under these conditions farmers do perceive some benefit from the rotation. The program has been carried out with generous rates of supply; however, if these were reduced to the approximate level of the water requirement, the weekly interval would probably prove to be too long.

Land Consolidation

The Land Consolidation Act of 1974 institutionalized a series of improvements designed to: (a) reallocate land so that farms comprise relatively few separate parcels which are oriented for efficient farm ditch layouts; (b) level most of the land; (c) construct field channels, roads, and drains; and (d) organize water user groups. The Act authorizes the Government to carry out these activities, and to collect part of the investment costs from the farmers beginning two years after construction is complete.

Land Consolidation Projects. Some 13,500 ha of land in the northern Chao Phya delta were developed according to this Act between 1973 and 1976. A Stage II project extended the same program to about 47,000 ha in the Central Plain between 1976 and 1982. Initial specifications for the land consolidation program called for field ditch, road, and drain densities between 35 and 45 m/ha. Each farm had direct access to a field channel, road, and drain. Field channels were designed for at least 1.3 liter/sec per ha, about 50% greater than the capacity of the main system. The cost of the program in 1980 prices was about $900/ha, of which about 40% comprised the cost of land leveling. The Stage II Chao Phya project was intended to use design standards resulting in less costly works for part of the project area. Experience to date indicates some difficulty in applying the revised design standards. The major difference between the two models was that land leveling was largely omitted from the less expensive one. Those parts of the Central Plain where it was tried were mostly subject to deep flooding in the wet season, reduced access to water in the dry season, or both.

The 95,000-ha Phitsanulok project was developed beginning in 1976, with three intensity levels of land consolidation. About one fourth of the
project area was provided with the most intensive form of consolidation, about half was provided with a similar model except that general land leveling was omitted, and the remainder was provided with facilities suitable for field-to-field irrigation. In the Northeast, some 10,000 ha were consolidated, about half at the most intensive level ($1,150/ha) and half at the intermediate level.

6.14 Other models have also been tried on a pilot basis combining what were considered optimal standards for the various elements. In general, the most intensive forms of land consolidation have been carried out in areas where water can be provided reliably throughout the dry season and where flooding depth in the wet season is not a serious deterrent.

6.15 Water user groups have been formally established in land consolidated areas of the Central Plain and the Northeast, but they have not yet become viable institutions. Their major purpose is to help farmers organize the distribution of water and maintenance activities, but these purposes do not appear to be important enough to the farmers to sustain high levels of commitment and involvement.

6.16 Farmer Acceptance. After only a brief period of hesitancy, farmers have strongly supported land consolidation, especially its most intensive model. Their enthusiasm could be explained by: (a) greater reliability in the supply of water at the FTO throughout both seasons; (b) increased likelihood of having dry season irrigation; and (c) higher land values. But as the following indicates, these benefits (although real) do not entirely derive from the land consolidation itself:

(a) The yield of dry season paddy is significantly higher in the consolidated areas than outside them, but yield differences among the different models of consolidation are often not significant. Furthermore, there is reason to believe that yield differences between consolidated areas and areas which are unconsolidated but which receive the same quantity of water at the FTO are also not significantly different. Land consolidation at the tertiary level is usually accompanied by upgraded management and sometimes upgraded design of the main systems resulting in more reliable FTO supplies.

(b) All the land consolidation projects were justified by dry season benefits accruing every year. In the Greater Chao Phya project, however, there is enough water for dry season paddy on only about 35% of the area. Up to now, farmers in consolidated areas have clearly benefited from the program by double cropping nearly every year. As consolidation proceeds, there is progressively less unconsolidated land receiving dry season water. This also accounts for the remarkable increase in land values in consolidated areas. The fact that farmers clearly prefer the most intensive model of development reflects at least in part their expectation that the greater degree of development is associated with a stronger dry season "water right."
(c) Land values have approximately doubled in many areas where land consolidation has been carried out. Because crop diversification has not occurred on a large scale in these areas, the increased land values are primarily a reflection of the increased reliability of water and greater likelihood of dry season cropping discussed above.

6.17 Consolidation is also a costly process for government and does not necessarily lead to sought-for changes in the cropping pattern. Although the statutory two-year grace period prior to farmer repayment has passed in many areas, farmers have not yet begun making significant payments against the capital cost of land consolidation. Further crop diversification has not been greatly increased by the program, and there is evidence that the slightly higher rice yields in consolidated areas are produced because of more water supplied.

6.18 In summary, the Government's search for less expensive forms of land development is well advised. Experience to date indicates that benefits from consolidation are not derived from increased paddy yields. Consolidation benefits and farmer support of the program are instead mainly related to the unofficial but de facto improvement in access to dry season water, both in terms of assured cropping every dry season and more nearly adequate supply at the FTO throughout the season. The increase in land values is associated with improved access to water. Other benefits include aggregation of fragmented plots into larger holdings, provision of tertiary roads, and somewhat reduced flooding hazard in the wet season.

New Approaches in Tertiary Design and Management

6.19 Tertiary systems in Thailand must supply water appropriate to the needs of paddy, require relatively little operational and maintenance attention from farmers and irrigation staff, and function effectively within the constraints posed by the main system. Many tertiary systems, especially those in the Northeast and North, should have the capability to supply non-paddy crops efficiently in the dry season, or the ability to do so in the future with relatively minor changes. This section describes some of the more promising ways to design and operate tertiary systems under Thai conditions. It is concerned with tertiary systems of existing projects except where new projects are explicitly referred to.

6.20 Annual Rotation. An important choice in tertiary design and operation is whether to pro-rate the limited water supply in the dry season to the whole project area, or to supply water only to that part of the project area that can be supplied adequately. Pro-rated supply to the greater Chao Phya project area would result in supply over the whole area equal only to about one third its water requirement for rice. Farmers would have to allocate the shortage among themselves. While this model is widely used in North India and Pakistan, and under certain conditions may result in productive water use, it introduces a number of problems such as the need for (a) a highly developed tertiary network to deliver water within the service area; (b) an effective decision-making system among farmers to promote equity; (c) provision of relatively high water supplies for dry season rice; and (d) ways to rotate water use within the system to enable operation based on design flows during scheduled periods.
6.21 For two years, RID has implemented a limited annual rotation in the Central Plain with the objective of continuously supplying the full design flow to selected service areas. The program substitutes administrative rationing of limited water within the main system for farm level rationing. Preliminary results indicate that farmers are prepared to accept an annual rotation, but that strong and sustained political support is a prerequisite to its success. Advantages of an annual rotation program are: (a) the tertiary system can be designed and operated based on a common system appropriate for both the wet and dry season; (b) there is less cause for conflict among farmers within service areas and among nearby service areas which are competing for scarce water; and (c) rice, the most common crop in both seasons, can be grown productively or not at all.

6.22 Paddy yields are extremely sensitive to the rate of water supply when that rate is about equal to the rate of evaporation. At higher rates of supply, further increase in yield is negligible because the full water requirement has already been met. The optimum rate of water supply is thus enough to supply the full requirement but no more. This rate depends upon the rate of evaporation, S&P requirements and efficiency losses, and in general is easier to supply with an annual rotation than with a pro rated supply. Farmers with a pro rated supply are under pressure to spread the water over as much of their land as possible, with excessive losses through edge effects where rice is not grown.

6.23 Annual rotations provide water on a more certain basis, which is a strong inducement for farmers to use modern inputs and greater management care. Where the supply of water to individual farms is unpredictable or subject to conflicting interests, farmers tend to avoid modern inputs, especially those requiring cash expenditures. Yields of dry season paddy are highly sensitive to such inputs, especially fertilizer, weeding and variety.

6.24 An annual rotation at the lateral or distributary level can also alleviate the problem of inadequate canal capacities in the main system. It would not require greater capacity in the main canal than that which already exists. Annual rotations comprising different service areas at the FTO level would relax the capacity constraint at both the main canal and lateral levels, but it does not appear practical at present to enforce an annual schedule of closure at the FTO level.

13/ Yield response curves for upland crops have the familiar shape of yields increasing at a progressively slower rate until diminishing returns set in. For paddy, the yield response is steep and production per unit of water is greatest where the potential water requirement is just met; beyond that, the curve is essentially horizontal.

14/ Because of capacity constraints in existing systems especially in the Chao Phya project, it is usually not possible to supply the full dry season water requirement for rice with rotational operation of the main system.
6.25 Farmer Organization. People's Irrigation Projects in the Northern Region are operated and maintained largely by farmers (para. 4.25). Although some of their initiative may have been lost in recent years, farmers still take responsibility for many of their systems. The RID has tried to find ways of assisting these and nearby projects without disturbing traditional farmer organizations.

6.26 Experience in the North is sometimes taken as an indication that farmers can be organized to look after irrigation in other projects in Thailand. Although there are underlying relationships which may be of use, conditions elsewhere in the country are different and the transferability of experience from the North is not high.

6.27 The main reason farmers continue to be well organized in People's Irrigation Projects is because the primary purpose of the organization is to acquire water at the source. Although farmers have responsibilities at the tertiary level, it is clear that the major reason for organizing is to maintain the inlet of the main canal and the bamboo weir so that the system takes in the water to which it is entitled. These activities are carried out with careful planning and ceremony. The RID has wisely refrained from intervening in these projects to avoid disrupting the farmers' organization. However, some improvements such as construction of gated intakes and strengthening of bamboo weirs by gabions or steel piles would alleviate the need for farmers to periodically carry out repairs.

6.28 Farmer organization for the major projects in Thailand is envisaged in terms of distributing water at the tertiary level, maintaining the tertiary system, and paying for irrigation services more efficiently. It is doubtful that these functions are perceived important enough by individualistic farmers to bind them into tightly organized groups like those of the North. At a minimum, successful farmer organizations should at least have the power to represent the group in negotiating and maintaining their share of water at the outset point.

6.29 Size of Service Area. The size of service areas in most Thai systems is a result of how the main system was designed, e.g., the spacing between lateral canals, and not of conscious decisions about optimum size. There is evidence that many service areas are too large to permit timely irrigation throughout their commands, with the result that water is wasted and yields reduced. The size criteria should be based both on the number of farmers and on total area, not by area alone. Between 20 and 25 farmers per service area may be an optimum number for tertiary irrigation performance; this would result in areas of 50 to 60 ha maximum size for most of the country. Service areas of this size have been found relatively efficient and manageable in the Philippines under conditions similar to those of Thailand.

6.30 Tertiary Design. Tertiary ditch networks are usually discussed in terms of minimum ditch length per ha served, but there is little evidence what an optimum density in rice irrigation is, or even whether there is an optimum level under conditions of irrigated tropical rice. Design of the tertiary system should consider (a) the FTO, (b) the initial ditch reach leading to the service area, and (c) the tertiary network.
6.31 The most important prerequisite to satisfactory performance of each tertiary system is to deliver target rates of flow through its FTO. At most, the actual discharge may be 20% more or less than the target flow, and should not need frequent fine tuning, at least initially. The main impediments to delivery against target rates are: (a) many FTOs do not deliver at design rates because they are not designed for self-flow control or because of subsequent modifications by farmers; (b) fluctuations in water levels in lateral and minor canals result in severe distortion in flows through individual FTOs; (c) unauthorized FTOs have been built by farmers in response to local topography, variable water supply in the lateral, or service areas too large for timely supply; and (d) the means of estimating and controlling FTO discharge are not practical.

6.32 The constant head orifice (CHO) has been adopted by RID in many newer projects as a means to measure and control FTO flows, but experience has shown that it is not satisfactory where there is variation in head in the upstream canal, and because of complexity in operation. It has not been successfully used under similar conditions elsewhere in Southeast Asia. Because periodic adjustment of gates by irrigation staff is not practical, these structures impede rather than help in achieving the primary objective of supplying target flow rates.

6.33 Many service areas in Thailand, especially in the older projects of the Northeast, are supplied by FTOs which deliver into borrow pits before water can reach the main supply ditches. Borrow pits on at least one side of a canal may extend out to a distance from 2 to 15 m, and function both as drains and irrigation channels. An effective conveyance channel between the FTO and the supply ditch is essential where borrow pits exist.

6.34 Choices in designing and laying out tertiary networks are a matter of considerable discussion and experimentation in Thailand. Tentative observations to be reviewed by RID are as follows:

(a) The network must work efficiently for paddy, the dominant crop in both seasons;

(b) The network should permit the cultivation of non-paddy crops in areas where they are suitable, or be readily adapted to do so;

(c) RID should not design and build tertiary systems which require greater government responsibility in operations and maintenance at the tertiary level, but should design them in ways that farmers can easily operate; and

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15/ Specifying what the target should be is beyond the scope of this report, but is a comparatively straightforward problem. Techniques for estimating water requirements of crops and soils are considerably more accurate than the ability to deliver whatever rates may be selected.
Beyond a certain level, increased ditch density and rotational on-farm distribution create local problems of manageability and maintenance which farmers on their own will not resolve.

Conclusions

6.35 Intensive tertiary development has been recommended in the past in response to poor on-farm irrigation performance which, however, in large part stems from highly variable, unpredictable, and inadequate supplies of dry season water at the FTO. But unless the main system is improved simultaneously, the intensity of the tertiary network itself will not address this problem, and thus may not result in substantial improvements in irrigation performance.

6.36 Experience with various approaches to improving on-farm operations have indicated that:

(a) Where the supply of water is within the range of 75-125% of the total water requirement of paddy, field-to-field irrigation at the tertiary level is relatively efficient up to distances of 300 m or more. There is no evidence that overland water movement from one farm to another interferes significantly with its utility;

(b) Rotational application of water for paddy is not critical. The chances of successfully carrying out on-farm rotation are limited without considerable political and financial commitment from the government;

(c) Service areas ordinarily should not exceed the land operated by 20 to 25 farmers, which for much of Thailand means about 50 ha;

(d) Annual rotation should be instituted to limit the area irrigated in the dry season commensurate with the water available; the areas programmed for water would rotate each year;

(e) Each service area should be provided with a main farm ditch drawing water from a self-controlled FTO. The ditch should be designed to command distant and higher portions of the service area, and not according to standardized density norms. In some cases, the density may exceed that of intensive land consolidation, but in others it will be much less; and

(f) Where irrigated areas are suitable for upland crops, such as in the Northeast and parts of the North, the main system in those areas should be able to provide intermittent water supply to the service areas, which would prevent saturated soils from interfering with crop production. Field channels for these systems would be constructed by the RID but overall responsibility for a tertiary network suitable for rotational irrigation should remain with the farmers, following government promotion.
6.37 The RID should attempt to identify through field evaluations in existing project areas the benefits from each form of tertiary development, and the requirements for its successful implementation.
### Thailand: Basic Hydrological Data of Major River Basins

#### Chao Phya Basin

<table>
<thead>
<tr>
<th>Drainage Area at</th>
<th>Area (sq km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhumipol Dam on Ping River</td>
<td>26,400</td>
</tr>
<tr>
<td>Sirikit Dam on Nan River</td>
<td>13,200</td>
</tr>
<tr>
<td>Chainat Dam</td>
<td>90,100</td>
</tr>
</tbody>
</table>

Average annual rainfall over river basin: 1,000-1,400 mm

<table>
<thead>
<tr>
<th>Location</th>
<th>Average Runoff</th>
<th>Maximum Runoff</th>
<th>Minimum Runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>River mouth</td>
<td>30,300</td>
<td>48,500</td>
<td>15,500</td>
</tr>
<tr>
<td>Bhumipol Dam</td>
<td>6,580</td>
<td>9,140</td>
<td>3,260</td>
</tr>
<tr>
<td>Sirikit Dam</td>
<td>5,970</td>
<td>10,000</td>
<td>2,780</td>
</tr>
</tbody>
</table>

#### Mae Klong Basin

<table>
<thead>
<tr>
<th>Drainage Area at</th>
<th>Area (sq km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Srinagarind Dam on Quae Yai River</td>
<td>12,400</td>
</tr>
<tr>
<td>Khao Laem Dam on Quae Noi River</td>
<td>3,720</td>
</tr>
</tbody>
</table>

Average annual rainfall over river basin: 2,000 mm

<table>
<thead>
<tr>
<th>Location</th>
<th>Average Runoff</th>
<th>Maximum Runoff</th>
<th>Minimum Runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>River mouth</td>
<td>13,400</td>
<td>24,400</td>
<td>7,800</td>
</tr>
<tr>
<td>Srinagarind Dam</td>
<td>4,580</td>
<td>7,540</td>
<td>2,800</td>
</tr>
<tr>
<td>Khao Laem Dam</td>
<td>5,200</td>
<td>9,900</td>
<td>2,130</td>
</tr>
</tbody>
</table>

Mean Annual Runoff Expressed in Depth

- At river mouth: 406 mm
- At Srinagarind Dam: 381 mm
- At Khao Laem Dam: 1,397 mm
### Mekong Basin

#### Mekong River

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total drainage area</td>
<td>795,000 sq km</td>
</tr>
<tr>
<td>Drainage area at the Thailand-Laos-Burmese border (Chiang Saen)</td>
<td>189,000 sq km</td>
</tr>
<tr>
<td>Drainage area at Vientiane</td>
<td>229,000 sq km</td>
</tr>
<tr>
<td>Drainage area at Kratie (Kampuchea)</td>
<td>646,000 sq km</td>
</tr>
<tr>
<td>Average annual rainfall over river basin</td>
<td>1,380 mm</td>
</tr>
</tbody>
</table>

#### Average Annual Runoff

<table>
<thead>
<tr>
<th>Location</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>At Burmese border</td>
<td>87,300 mln. cu m</td>
</tr>
<tr>
<td>At Vientiane</td>
<td>150,000 mln. cu m</td>
</tr>
<tr>
<td>At Kratie</td>
<td>467,000 mln. cu m</td>
</tr>
</tbody>
</table>

#### Average Annual Discharge

<table>
<thead>
<tr>
<th>Location</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>At Burmese border (1961-63)</td>
<td>2,770 cu m/sec</td>
</tr>
<tr>
<td>At Vientiane (1923-44 and 1948-63)</td>
<td>4,575 cu m/sec</td>
</tr>
<tr>
<td>At Kratie (1933-44, 1946-53 and 1960-63)</td>
<td>14,80 cu m/sec</td>
</tr>
</tbody>
</table>

#### Maximum Flood Discharge

<table>
<thead>
<tr>
<th>Location</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>At Burmese border</td>
<td>11,900 cu m/sec</td>
</tr>
<tr>
<td>At Vientiane</td>
<td>20,800 cu m/sec</td>
</tr>
<tr>
<td>At Kratie</td>
<td>67,000 cu m/sec</td>
</tr>
</tbody>
</table>

#### Minimum Discharge

<table>
<thead>
<tr>
<th>Location</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>At Burmese border</td>
<td>570 cu m/sec</td>
</tr>
<tr>
<td>At Vientiane</td>
<td>701 cu m/sec</td>
</tr>
<tr>
<td>At Kratie</td>
<td>1,250 cu m/sec</td>
</tr>
</tbody>
</table>

#### Mean Annual Runoff Expressed in Depth

<table>
<thead>
<tr>
<th>Location</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>At Burmese border</td>
<td>460 mm</td>
</tr>
<tr>
<td>At Vientiane</td>
<td>655 mm</td>
</tr>
<tr>
<td>At Kratie</td>
<td>722 mm</td>
</tr>
</tbody>
</table>

#### Mun Basin

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total drainage area at mouth of Mekong River</td>
<td>119,573 sq km</td>
</tr>
<tr>
<td>Drainage area of Ubon Ratchathani (mouth of Chi River)</td>
<td>106,798 sq km</td>
</tr>
<tr>
<td>Average annual rainfall upstream of Ubon Ratchathani</td>
<td>1,469 mm</td>
</tr>
</tbody>
</table>

#### Average Annual Runoff (1969-1980)

<table>
<thead>
<tr>
<th>Location</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mun at mouth of Mekong River</td>
<td>28,575 mln. cu m</td>
</tr>
<tr>
<td>Mun at Ubon Ratchathani</td>
<td>21,266 mln. cu m</td>
</tr>
<tr>
<td>Chi at mouth</td>
<td>10,088 mln. cu m</td>
</tr>
<tr>
<td>Table 1</td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Mun at mouth of Mekong River</td>
<td>Mun at Ubon Ratchathani</td>
</tr>
<tr>
<td>910 cu m/sec</td>
<td>9,876 cu m/sec</td>
</tr>
<tr>
<td>Mun at Ubon Ratchathani</td>
<td>Chi at Yasothon</td>
</tr>
<tr>
<td>677 cu m/sec</td>
<td>2,380 cu m/sec</td>
</tr>
<tr>
<td>Chi at mouth</td>
<td></td>
</tr>
<tr>
<td>321 cu m/sec</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Minimum Average Discharge</strong> (1980)</th>
<th><strong>Mean Annual Runoff Expressed in Depth</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mun at mouth of Mekong River</td>
<td>Mun at mouth of Mekong River</td>
</tr>
<tr>
<td>97 cu m/sec</td>
<td>238 mm</td>
</tr>
<tr>
<td>Mun at Ubon Ratchathani</td>
<td>Mun at Ubon Ratchathani</td>
</tr>
<tr>
<td>60 cu m/sec</td>
<td>199 mm</td>
</tr>
<tr>
<td>Chi at mouth</td>
<td>Chi at mouth</td>
</tr>
<tr>
<td>52 cu m/sec</td>
<td>205 mm</td>
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**Bang Pakong Basin**

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<td>Mean annual runoff expressed in depth</td>
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<tr>
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</tr>
<tr>
<td><strong>Harvested area ('000 ha)</strong></td>
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<tr>
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<tr>
<td><strong>Yield (ton/ha)</strong></td>
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**Major Rice Crop**

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<td>6,636/c</td>
<td>7,514/c</td>
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<td>8,519</td>
<td>8,137</td>
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<td>9,098</td>
<td>9,100</td>
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<tr>
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<td>15,758</td>
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<tr>
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<td>1.65</td>
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<td>1.61</td>
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**Second Rice Crop**

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<td>3.32</td>
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/a Yield calculated on harvested area.

/b Yield calculated on planted area.

/c Harvested areas for years 1971/72 to 1973/74.

Source: Agricultural Statistics of Thailand, Office of Agricultural Economics, MOAC.
### Table 3

**Thailand: Trends in Rainfed and Irrigated Paddy - Area, Production and Yield of Major Rice Crop by Region, 1974/75 - 1981/82**

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<td>15,758</td>
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Source: Agricultural Statistics of Thailand, Office of Agricultural Economics, MOAC.
### Thailand: Trends in Rainfed and Irrigated Paddy - Area, Production and Yield of Second Rice Crop by Region, 1974/75 - 1981/82

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Source: Agricultural Statistics of Thailand, Office of Agricultural Economics, MOAC.
### Inventory of Irrigation Projects in Thailand by Region

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<th>Regional headquarters</th>
<th>River basin</th>
<th>Service area (ha)</th>
<th>Irrigated area (Hectares % of total)</th>
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/a Completed and under construction.
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<td>Petchaburi</td>
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<td>Pranburi</td>
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<td><strong>Subtotal</strong></td>
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<td></td>
<td>Kolok</td>
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<td>West Coast</td>
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<td></td>
<td><strong>Total</strong></td>
<td><strong>3,642,198</strong></td>
<td><strong>2,883,461</strong></td>
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Source: Water Resources Development in Thailand (completed to the end of 1979 and under construction in 1980), Royal Irrigation Department, Program Coordination and Budget Division, Statistics and Progress Report Section, December 1980.
<table>
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<th>River basin</th>
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<td>Chi</td>
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<td>Ping (downstream of Bhumipol)</td>
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/a Completed and under construction.

Source: Water Resources Development in Thailand (completed to the end of 1979 and under construction in 1980), Royal Irrigation Department, Program Coordination and Budget Division, Statistics and Progress Report Section, December 1980.
### Inventory of Medium-Scale Irrigation Projects in Thailand /a

<table>
<thead>
<tr>
<th>RID region</th>
<th>Number of projects (Run of river)</th>
<th>Irrigated area (hectares) (Run of river)</th>
<th>Stor- age</th>
<th>Pump- ing</th>
<th>Total</th>
<th>Storage</th>
<th>Pumping</th>
<th>Total</th>
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<td>6</td>
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</table>

| Total      | 72                              | 301,588                                 | 105,744   | 20,000    | 113   |         | 427,332 |

/a Irrigated areas between 1,000 ha and 20,000 ha.
### Inventory of Main Storage and Diversion Dams by River Basin in Thailand

(Capacity over 50 million cu m)

<table>
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<th>Basin</th>
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<th>Catchment area (sq km)</th>
<th>Average annual inflow (mln cu m)</th>
<th>Average annual runoff (mln cu m)</th>
<th>Total active capacity (mln cu m)</th>
<th>Installed capacity (MW)</th>
<th>Year of completion</th>
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<td>1980</td>
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</tbody>
</table>

/a Design.
/b Start of construction.
Annex 1
Thailand's Resource Base

1. Climate. North, Northeast and Central Thailand are dominated by the southwest monsoon, with rainfall concentrated from mid-May through October and peak monthly rainfall in September. The total amount and distribution of rain is similar for the three regions and is adequate for a wet season rice crop. In practice, wet season rainfall distribution may vary considerably from year to year. The Northeast Region has the most unreliable pattern of rainfall. The monsoon may arrive late, finish early or weaken for two to three weeks during the growth of the crop, leading to considerable year-to-year variations in yield and production of rainfed rice and upland crops. While rainfall is more reliable in the Central and Northern Regions, a two- to three-week dry spell in June-July, which may be critical for newly transplanted crops, is quite common. Supplementary wet season irrigation is useful in all regions to facilitate timely planting, reduce flood damage, allow production of a second crop on residual soil moisture and assure reasonable yields. From November to April these regions are dominated by a northeasterly air stream which brings cool dry weather in December and January, and hot dry weather in March and April. The limited rainfall during the period is irregular and unreliable. Potential evapo-transpiration exceeds rainfall for six to eight months and annual field crops cannot be grown without irrigation.

2. The Southern Region has a different rainfall pattern. Total annual rainfall is much higher, ranging from 1,760 mm at Surathani to 4,350 mm in Ranong. Average precipitation in other parts of the region ranges from 2,100 - 2,600 mm. The northeast monsoon brings high intensity rainfall in October-January when over 50% of annual rainfall may occur. This is the main rice growing season. The February-April period is usually too dry to sustain annual crop production. Although rainfall increases in the May-September period, the influence of the southwest monsoon is weak on the eastern side of the peninsula where most rice is grown. This dry season rainfall is too unreliable to sustain a second rice crop, but rainfed upland crops are possible. In spite of the high total rainfall, irrigation is needed to achieve satisfactory yields and to allow double-cropping. In the wet season (October-January), supplementary irrigation facilitates early planting and reduces the risk of damage from heavy rains and flooding during November and December. Reliable rice production is impossible without irrigation in the February-August period.

3. Temperature is high and relatively uniform throughout the year in all regions and is generally favorable for year-round crop production. Peaks of 35-40°C usually occur in March and April with average lows of 16-20°C from November to January. Temperature variation is much lower in the South. In the Central, Northern and Northeastern Regions, altitude modifies the temperature regime considerably. In the cool season, lows of 5-6°C have been recorded at Udon Thani and Uttaradit, with 8°C at Nakhon Sawan. In exceptional years, low temperatures during flowering and seed development may result in a high percentage of empty panicles in the wet season rice crop. In
the highlands of the North, the temperature is low enough to permit production of temperate fruits and vegetables and vegetable seed. Day length varies from a maximum of 13 hours, 21 minutes at Chiang Rai (20°N latitude) to a minimum of 11 hours, 46 minutes in the extreme South (6°N), with day length variations of 2 hours, 26 minutes and 42 minutes, respectively, from winter to summer. Day length has little effect on field crop production, except that the North is more favorable for the local varieties of soybean currently available and is the only place where long-day vegetable seeds, such as cabbage and radish, can be grown. Radiation levels may occur in all regions during months of heavy rainfall, especially November-December in the South and August-September in the other regions.

4. Soils, Topography and Drainage. Northern Thailand is characterized by mountain ranges running north and south, interspersed with rolling uplands in the foothills and old levees and flood plains in the river valleys. The potential for irrigation and intensive cropping is largely restricted to the lowlands which represent only about 10% of the total land area. There is thus considerable pressure on this land, and where dry season water is available, most of it is double-cropped. The lowlands consist of deep recent river alluvium with a typical levee-basin landscape. With the exception of the slowly permeable clay basin or back swamp areas, the soils have moderate-to-good internal drainage and a reasonable slope which facilitates irrigated upland crop production in the dry season without heavy investment in intensive drainage and water distribution facilities. Land classification data for some irrigated lowland areas indicate that over half the soils may be suitable for dry season irrigated upland crops. Heavy rains in the wet season regularly flood most lowland areas, and rice is the only practical wet season crop. Slash and burn shifting cultivation in catchment areas has increased the severity of flooding in the wet season and water shortage in the dry season in some streams. The extent of this problem is unknown, but should be assessed as part of any water resource investigation.

5. The Northeast includes about one third of the total land area of Thailand and 30% of the population. The bulk of the agricultural area is a raised plateau some 120-200 m above sea level. The area has moderately rolling topography with a predominance of low humic gley, gray podzolic and red yellow podzolic soils with laterite. Most soils have low water holding capacity and poor reserves of plant nutrients. They are not well suited to annual crop production without substantial inputs of fertilizer or the adoption of a stable tropical pasture, legume-crop rotation incorporating livestock. Rainfed rice is grown in the depressions and lower slopes of the low, rolling hills. Kenaf and cassava are the major crops on the higher upland soils. The Region is not well endowed with water resources or river systems. Heavy alluvial soils well suited to rice production are limited to the flood plains of the Mekong, Mun, Chi and several small rivers, and account for less than 8% of the Region's potential rice land. The possibility of flooding largely restricts the use of these soils to rice in the wet season. However, a large part of these areas are suitable for dry season upland crops with irrigation. Drainage is not a major problem in the Northeast apart from local depressions. Flood damage to rice crops is largely limited to the flood plains of the Mekong and small parts of the flood plains of the local river systems.
6. The South is characterized by a series of mountain ranges running in a general north-south direction. Land suitable for field crops is limited to the foothills, the valleys of the numerous rivers flowing east to the Gulf of Thailand, small areas of flat-to-rolling land on the west coast and larger coastal plain areas on the east coast. However, parts of the river flood plains are only moderately suitable for lowland rice due to unfavorable topography or soil texture. In addition, portions of the coastal plains comprise beach sands, peat swamp and acid brackish water alluvium which have limitations for irrigated crop production. The availability of suitable soils is thus a basic constraint to extensive irrigation development in the South. Even where soils are suitable, flooding caused by a combination of high intensity rainfall in the monsoon season and poorly drained, flat flood plains, significantly lowers rice yields in many areas. Salt water intrusion in lower-lying coastal plains during the dry season also precludes irrigation.

7. The Central Region contains the two major river basins in Thailand, the Chao Phya and Mae Klong. It is the most populous, prosperous region and the major area for surplus rice production. Mountains, foothills and rolling plains border the region to the northeast and west, but the main topographical features are the flood plains of the Chao Phya. These are extended to the east by the Bang Pakong and Prachin Buri Rivers and to the west by the Mae Klong. The combination of a large catchment area and flat grade leads to regular, extensive flooding in the southern Central Plain from July through January. Flooding also occurs in the lower-lying portions of the Mae Klong and Bang Pakong basins. At present, there is no economically viable engineering solution to the wet season flooding and drainage problems of the southern Chao Phya due to the vast quantities of water to be handled and the low grade.

8. The soils of the Nan, northern Chao Phya and northern Mae Klong basins are mainly semi-recent and recent alluvia deposited in a typical riverine levee-flood plain sequence. Heavy soils of low permeability predominate. Land classification data and experimental evidence indicate that only 20-30% of these soils are suitable for dry season irrigated upland crops. The soils of the southern Chao Phya are dominated by medium-to-heavy clays developed on brackish water deposits, and a broad band of heavy clay soils developed on marine deposits along the coast. Portions of the heavy soils around Bangkok and in the southern portion of the Mae Klong area have been successfully developed for tree crops, grapes and vegetables. This involves the intensive development of raised beds which can only be justified for high return cash crops. As a result of regular wet season flooding, all but the levee soils must be planted to rice in the wet season. Due to soil conditions, rice is likely to be the main irrigated dry season crop as well, except in selected areas like the Mae Klong and the Sam-Chook area of the Chao Phya plain where well drained levee soils favor sugarcane and upland crops. There is also potential for growing short duration crops like mungbean on residual moisture after wet season rice.

9. The irrigable areas in Thailand are relatively free of serious soil problems with the exception of some acid sulphate soils in the southern Chao Phya and limited areas of salinity in the coastal region of the South, Petchaburi in the southwestern Central Region, and in small areas of the North
and Northeast. Nevertheless, most soils have low fertility. Fertilizer response experiments with rice for the Central and Northern Regions indicate a marked response to nitrogen with an occasional response to phosphate. Good responses to lime are sometimes achieved on the acid sulphate soils. In the Northeast and South, a combination of nitrogen and phosphate usually gives profitable responses, and potassium may be required in some areas. Yields without fertilizer are surprisingly high, especially in portions of the Central Plain. Evidence is accumulating which indicates that large quantities of nitrogen are fixed by free living organisms in the lowland rice situation in Southeast Asia. Preliminary results at Chainat indicate that this may be on the order of 30 kg/ha of nitrogen per season. This free source of native nitrogen warrants more investigation as successful exploitation could reduce production costs considerably.
Annex 2

Agricultural Issues and Their Impact on Water Use and Irrigation System Operation

1. There are many ways in which farming practices are influenced by the design and operation of irrigation systems, including the on-farm system. This annex discusses selected agricultural issues in Thailand in terms of on-farm water use and operation of the main system.

2. The issues discussed are: (a) water requirements for rice and the effects of land preparation, planting method, rice variety, and seepage and percolation (paras. 3-25); and (b) irrigation for diversified crops in the dry season following rice (paras. 26-43).

Paddy Water Requirements: Land Preparation, Varietal Effects, and Seepage and Percolation

3. The design of all but the most recent irrigation systems in Thailand is based on relatively low water requirements for rice during the wet season. Because there is now a strong demand for dry season irrigation, it is useful to analyze the several components of the total water requirement, and show how they are affected by different assumptions such as the method of crop establishment (transplanting or broadcasting), variety of rice, and rates of seepage and percolation (S&P) into the soil.

4. Land Preparation. For given soil and climatic conditions there is a daily rate of water supply adequate to satisfy the water requirements of a growing crop, soil losses through S&P, and field losses. During land preparation, however, there is no single rate of water required for plowing and puddling. The land preparation water "requirement" is instead a range of values dependent on the duration of the land preparation period.

5. The only strict requirement for water in land preparation is the amount needed to saturate the top 30 cm of soil during plowing and puddling, which depends upon the initial moisture content and physical properties of the soil. For heavy clay soils like those of the Chao Phya delta, the saturation requirement is equal to about 150 mm if the soil is already moist from a previous crop, and about 350 mm if it is thoroughly dried out. Comparable figures for Northeast Thailand, where the soils have less clay, have not been established but may be estimated at about 100 and 200 mm.

6. Table 1 shows how the total water used for land preparation changes in response to different assumptions for initial soil moisture content (moist or dry), different seasons (wet or dry), and different periods of land preparation (60-day and 30-day durations).
Table 1: ESTIMATED APPLICATION DEPTHS OF WATER FOR LAND PREPARATION IN THE CHAO PHYA PROJECT /a

<table>
<thead>
<tr>
<th>Land preparation period:</th>
<th>60-Day Duration mm</th>
<th>30-Day Duration mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial soil condition:</td>
<td>Moist</td>
<td>Dry</td>
</tr>
<tr>
<td>Wet Season</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil saturation</td>
<td>150</td>
<td>350</td>
</tr>
<tr>
<td>Evaporation</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Seepage and percolation</td>
<td>45</td>
<td>90</td>
</tr>
<tr>
<td>Total (mm)</td>
<td>285</td>
<td>530</td>
</tr>
<tr>
<td>(l/sec/ha)</td>
<td>0.55</td>
<td>1.02</td>
</tr>
<tr>
<td>(l/sec/rai)</td>
<td>0.09</td>
<td>0.16</td>
</tr>
<tr>
<td>Dry Season</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil saturation</td>
<td>150</td>
<td>350</td>
</tr>
<tr>
<td>Evaporation</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Seepage and percolation</td>
<td>45</td>
<td>90</td>
</tr>
<tr>
<td>Total (mm)</td>
<td>375</td>
<td>620</td>
</tr>
<tr>
<td>(l/sec/ha)</td>
<td>0.72</td>
<td>1.19</td>
</tr>
<tr>
<td>(l/sec/rai)</td>
<td>0.12</td>
<td>0.19</td>
</tr>
</tbody>
</table>

/a Evaporation of water from the surface of the land undergoing preparation, and from S&P through the soil, is assumed to occur over the whole area for half the land preparation period (it normally takes two to three weeks for water to reach the tail-end of a service area). Evaporation rates are assumed to average 3.0 and 6.0 mm/day in the wet and dry seasons, respectively. S&P rates are assumed to average 1.5 and 3.0 mm/day (paras. 16-25).

7. The results show that shortening the land preparation period from 60 to 30 days reduces by more than 20% the water used for land preparation, but the shorter period requires greater rates of supply and consequently greater canal capacities. The highest rate needed for the 60-day period is about 0.19 l/sec/rai in the dry season, which is almost 50% greater than the design capacity of the main canals. A 30-day land preparation period is within the canal capacity (0.13 l/sec/rai) only in the case of moist soils in the wet season.

8. The results discussed above do not account for field efficiency losses, which are normally quite low for land preparation because of the capacity of the soil to absorb large amounts of water, and because almost all excess water spilled from higher farms is used on those farther down in the service area. The data also do not include water supplied by rainfall.
To summarize, the water required for land preparation is a function of the duration of the land preparation period, with longer duration causing greater water use. Shorter periods require less total water, but at higher rates of supply. Where farm turnout (FTO) flows are constrained by the design capacity of the main canals as in the Central Plain (0.13 l/sec/rai), land preparation cannot be completed in much less than 60 days in the absence of rainfall. The corresponding duration in Northeast Thailand is about 45 days.

Transplanted vs. Broadcast Rice. Until recently the great majority of irrigated rice in Thailand was grown in nurseries and transplanted after 30 to 40 days. In the 1970s, however, it became apparent that broadcast (direct seeded) rice gives yields equal to transplanted culture provided certain conditions are met. These are:

(a) the seed should be pregerminated for 24-36 hours before sowing to aid crop establishment;

(b) the fields should be leveled very carefully to avoid dry and flooded areas; and

(c) farmers must have access to carefully controlled quantities of irrigation, especially in the first 4 to 6 weeks after seeding.

In a study conducted in Chachoengsao Province, in the southern Chao Phya project, over 75% of the farmers had shifted to broadcast rice for the 1975 dry season crop. Mean yields for those farms and for transplanted farms were equal (2.8 t/ha), but there were greater yield variations for the broadcast group.

The major reason farmers shift to broadcast seeding is to save labor. Labor constitutes 32% of the total cost of producing transplanted rice but only 23% for broadcast rice. In some areas of the Central Plain agricultural labor at transplanting times has become extremely limited. Although direct seeding uses two to three times as much seed as transplanted rice and is believed by farmers to require more fertilizer for equal yields, farmers stand to increase their net returns by about 20% over transplanted rice, at current prices of labor, inputs and rice.

Shifting from transplanted to broadcast rice production increases the total water required slightly. The water used for land preparation is essentially the same for both methods. Transplanting 30-day old seedlings results in only 20 days less time in the field, compared with direct-seeded rice, because transplanted rice takes about 10 days longer to mature than direct-seeded rice. Furthermore, dates of planting are likely to be staggered over a longer period for transplant farmers because of labor constraints and problems of timing the nursery with land preparation. Based on the assumptions regarding S&P and evapo-transpiration (ET) (para. 16), the increased water requirement for broadcast rice relative to transplanted rice ranges from 150 to 180 mm in the dry season, and 100 to 130 mm in the wet season, other factors remaining constant.
14. Of more importance than the increased water requirement for broadcast rice is the need for more precise control over the water. Areas where the practice has spread the fastest are those where farmers control the supply of water to their fields by pumping. They thus prevent flooding and water shortage by supplying water when they want it.

15. **Effect of Shorter-Seasoned Varieties.** The Rice Division of the Agriculture Department has released the rice variety RD25 which matures in less than 100 days. It has been quickly adopted by many farmers in the dry season, but its long-term viability is threatened by susceptibility to diseases, especially rice blast. Nevertheless, the Rice Division is almost certain to release within five years other varieties of about 90 days growth duration which will be suited to the Central Plain in the dry season. Reducing the growth duration by 30 days will reduce the dry season water requirement after land preparation by about 23% (between 240 and 285 mm) without having any effect on the rate of supply.

16. **Rates of Seepage and Percolation.** Water requirements for the growing rice crop are the sum of ET, S&P and field losses. ET can be estimated to within + or - 10% by class A evaporation pan data, or by more complex techniques. S&P cannot be predicted at present by any theoretical procedure, but can be measured in the field. The fact that very little field data on S&P are available in Thailand explains some of the differences of opinion regarding field water requirements.

17. Seepage and percolation are the lateral and vertical components, respectively, of water lost beyond the 30-cm rooting depth of rice. Seepage is relatively minor in large flat areas because most of it passes from or under one field to another. However, there are many natural drains and rivers dissecting most rice land, and net seepage to these drains is often substantial.

18. In studies conducted on puddled, relatively heavy clay soils in the Philippines, which are similar to those in the Northern Chao Phya delta, S&P rates were found to vary mainly in response to depth to the water table and physical properties of the soil. Rates in the dry season averaged about 50% more than those in the wet season because of greater water table depth and increased edge effects caused by limited dry season plantings within large blocks.

19. The largest source of variation in S&P is differentiated soils and topography along sections perpendicular to major rivers or drains. Thus, S&P along the narrow belts of river levee soils is as high as 15 to 20 mm/day, while in the back swamp areas it may be zero or even negative. A single S&P estimate should therefore not be used for operating the system and in some cases not for designing it either.

20. For purposes of planning, however, a weighted average S&P rate for the Northern Chao Phya delta may be on the order of 2.0 mm/day in the wet season and 3.0 mm/day in the dry season. S&P for the lower delta is 50 to 70% of these rates, while rates for the North and Northeast Regions are higher. The only field data for S&P in Thailand available to the mission comes from an
RID-supported study in the Lam Pao Project, which showed mean S&P losses in the 1979 dry season ranging between 2.1 and 4.2 mm/day, and averaging 3.3 mm/day. These data are believed to represent relatively low-lying areas with heavy soils; mean rates are probably higher.

21. The heavy clay soils of the Central Plain and bottom lands in the north become deeply cracked if they are allowed to dry out after being puddled. S&P rates increased dramatically—sometimes by more than tenfold—when partially cracked soils are flooded again. Water losses through cracked soils also remove substantial amounts of nitrogen from the root zone of the crop through leaching. The effect of cracking on S&P is largely irreversible until the soil is puddled again.

22. Excessive S&P from areas that have been allowed to dry out partially means that irrigation managers cannot expect to save water by withholding irrigation for more than a few days in the dry season. The subsequent and continued high losses of water will usually outweigh the short-term savings from that period.

23. Studies have also shown that S&P rates on puddled, heavy soils are essentially unaffected by the depth of water on the field. Leakage through paddy bunds increases geometrically with greater depth, but most of the increase is seepage among adjacent fields, not a net loss. Farmers often plaster bunds with mud to reduce bund leakage during land preparation.

24. Field techniques for measuring percolation are: (a) lysimeter analysis; (b) concentric cylinders; and (c) in situ field measurements. Lysimeters are generally not satisfactory because of the disturbed nature of the soil, whereas concentric cylinders have large edge effects relative to the area tested. The most practical and simplest technique at present appears to be careful daily measurement of water depth on a number of sample rice paddies. The subsidence of the water depth in a 24-hour period during which no rainfall, irrigation, or surface drainage occurs is the same for ET plus S&P. ET can be estimated from pan data or other techniques, and subtracted from this sum to give S&P estimates. Mean rates of S&P can be computed for many such days throughout a season.

25. In conclusion, S&P rates vary considerably along a cross section from river levee to back swamp. Typical S&P rates for river levees are in excess of 10 mm/day, for a total irrigation requirement of 18 mm/day (2.0 l/sec/ha). At the other extreme are service areas with insignificant S&P, and maximum total requirements of about 7 mm/day (0.8 l/sec/ha). Variation within large service areas also exists, with higher rates near the head of the tertiary ditch where soils are typically lighter and depth to the water table greater. Smaller S&P rates for lower lying farms at the tail-end of service areas help to offset the effects of paddy-to-paddy irrigation and the tendency of farmers at the head of a ditch to get a larger share of the flow.

Prospects for Diversified Cropping in Irrigated Areas

26. Historically, irrigation systems in Thailand have been designed for wet season rice because that is the dominant crop in the country, and because
it is the only crop which can accommodate temporary periods of deep flooding when the major systems of the Central Plain spread the river floodwaters over a wide area. Rice is also well adapted to the heavy clay soils of most agriculturally important parts of the country.

27. There is little scope for nonrice crops in the major irrigation commands during the wet season. About 50,000 ha of fruit and vegetable crops are now grown in the Southern Chao Phya project for which farmers pump water from canals, and some sugarcane is found on lighter and more steeply sloped land, but the combination of heavy soils, relatively flat and low-lying land, high humidity, and likelihood of flooding due to high intensity rainfall makes diversified cropping in irrigated areas very risky during the wet season.

28. Diversified cropping in the dry season has been practiced for many years on parts of irrigated commands, especially in the North. Groundnut, soybean and tobacco are major crops in both village and RID projects where dry season irrigation is reasonably predictable and dependable. In the 23,000 ha Mae Taeng Project in the North, rice was planted on about 10,000 ha in the 1975 dry season, and soybeans on less than 2,000 ha. But by 1982, the area planted to these crops was reversed, with soybean occupying more than 10,000 ha in the dry season. In other northern projects, tobacco and groundnuts, together with rice, are the dominant dry season crops.

29. There was relatively little dry season irrigation in the Central Plain until the 1960s when the Bhumipol and Sirikit storage reservoirs were completed. Experience of the late 1960s and early 1970s shows that farmers were reluctant to take up any dry season crop, even dry season rice, when water was first available. Area under irrigation during the period January-May increased from a negligible base in the early 1970s to 47,000 ha in the northern Chao Phya area by 1981. The growth of dry season cropping is even greater in the southern area. Almost all of this area is planted with dry season rice since it is usually more profitable to farmers than wet season rice.

30. In Northeast Thailand, the lag in farmers' interest in dry season irrigation is similar to that of farmers in the Central Plain. An increase in farmers' demand for dry season water is now underway, about fifteen years after the five major tanks began impounding water. However, Northeastern farmers are more receptive to diversified crops than are Central Plain farmers, partly because soils in the Northeast are better adapted to them.

31. Irrigated rice continues to be the crop most farmers prefer in the dry season for many reasons. Cultural practices are well understood and basically similar to those for wet season rice; marketability of the product is assured through well established channels; and perhaps most important, modern rice varieties have been made available to Thai farmers that have a yield potential in the dry season which is about 25% higher than that in the wet season. Provided irrigation is adequate, most modern rice varieties now planted in Thailand (RD7, RD9 and RD25) respond to higher levels of nitrogen and solar radiation in the dry season than the wet, and are less constrained by insect and disease damage. As the Rice Institute identifies more modern varieties suitable for soils and environments in which traditional varieties
are still widely grown, one may expect even greater interest by farmers in dry season rice relative to other crops.

32. There are three principal factors which control the extent to which farmers in Thailand grow diversified (nonrice) crops in the dry season; they are: (a) the nature of the water supply; (b) the nature of the soil and topography; and (c) the nature of the market.

33. **Water Supply.** Diversified cropping is attractive to planners and engineers because the water requirement for nonrice crops is less than that for rice. Adequate irrigation of dry season rice requires a daily supply at the farm of about 1.5 l/sec/ha, compared with about two thirds that for sugarcane and about half that for groundnut, soybean, maize and most other upland crops. A shift from dry season rice to upland crops would thus make cropping possible on twice the area currently producing rice. Most diversified crops also have more drought tolerance than does rice, i.e., yields of most upland crops are reduced relatively less than those of rice if the supply of water is less than the potential water requirement of the crop.

34. In respect of water, however, farmers are not guided in their choice of crop by possibilities of using less for the benefit of other project areas but: (a) by how well the supply of water is suited to the crop; and (b) by the work required to manage on-farm water distribution. In both these respects, Thai irrigation systems supply water more appropriately for rice than for most upland crops. Rice does well with continuous supply, the normal mode of supply is almost all systems, whereas upland crops cannot be grown unless intervals of relatively full supply are followed by scheduled periods of no irrigation. Rice fields are a satisfactory medium to convey water from areas near supply points to the farther fields, whereas diversified cropping requires a more intricate field channel network to bring water to each farm, and usually to each field. Upland crops must be served by a much more intensive field channel network, and for some crops by graded furrows, which are not necessary for rice.

35. In summary, diversified dry season crops require less water than rice, but greater control over the water. Dry season water is insufficient to irrigate most of the project areas, but control and management of water in both the main system and on-farm levels are even more limiting at present. In considering possible nonrice crops for the dry season, farmers evaluate primarily the prospects of profitability and adequate water control—periods and intervals of availability, reliability of supply, stream size, and protection from overirrigation, for example—and only secondarily the amount of water.

36. Lateral seepage from rice land sometimes creates saturated soil conditions on adjacent land which precludes upland cropping. Thus, a practical requirement for successful diversified cropping is that no major plantings of rice be made in the same service area under a FTO. There are many examples, especially in North Thailand and more recently in the Northeast, where farmers have agreed to plant whole commands to upland crops. A study of rice, sugarcane, and mixed rice-sugarcane outlet commands in part of the Mae Klong Project showed that farmers use inputs and improved production practices almost twice as intensively if they are in areas growing only rice, compared with
mixed rice-sugarcane areas. Yields of rice were 2.2 t/ha in areas growing only rice, compared with 1.6 t/ha in mixed areas. Sugarcane yields also declined from 39 t/ha in homogeneous sugarcane areas to 29 t/ha in mixed areas. Adverse effects of planting upland crops other than sugarcane adjacent to rice are more severe than those cited above because other upland crops are more sensitive to soil saturation than sugarcane is. However, it should be noted that successful intermixed cultivation of rice-upland crops has been observed in countries with adequate water control (Taiwan, the Red River delta).

37. **Land and Soils.** In general, first class irrigated rice land can be made to produce upland crops only at considerable cost. High clay content of heavy rice soils reduces the infiltration rate of water, makes upland cultivation impossible except under a narrow range of moisture conditions, and imposes a large power requirement for land preparation following lowland rice. With improvements and careful management, however, heavy rice land can produce satisfactory yields of upland crops. Between 3 and 6 t/ha of oranges are being produced annually from very heavy Rung Sit clays in the lower Chao Phya project, and numerous vegetables are grown on heavy soils near Bangkok.

38. Land improvements necessary for converting first-class rice land to productive upland crops are (a) creation of a series of beds 4 to 5 meters wide separated by ditches to raise the elevation of the land, (b) land consolidation which increases the surface drainage, irrigation, and road networks, and (c) flood embankments in some cases to keep out excess water and to protect the surface networks. Costs of developing land near Bangkok into a series of beds, which result in land values increasing by factors greater than three, are paid by the owner.

39. Land in Northeast Thailand has less clay content than that in the Central Plain, and is not as flat. It is thus suitable for upland crops, despite a lower fertility level than most of the alluvial soils of the Central Plain. Northern Thailand has a wide range of soil types and topography, but many of the irrigated valleys are relatively small, steep, and independently supplied with water, which facilitates crop localization.

40. In short, first class irrigated rice land can produce high yields of diversified crops in the dry season, but at substantial cost to farmers, the government, or both. Soils in the Central Plain usually do not have comparative advantage for upland crops in view of competitive production costs for rainfed cropping.

41. **Markets.** Thailand is fortunate in having one of the most dynamic agri-business environments in the world. It is largely in private hands, and strongly responsive to profits. One example of its strength is the dramatic growth of sugarcane in the Mae Klong project area during the early 1970s when sugar prices were high. Many small farmers shifted from rice to sugarcane during that period and sold their crop on contract to the new sugar plants. More recently the relative prices of sugar and rice have fluctuated, and farmers respond by shifting part of their farm between the two crops.
42. It is therefore difficult to accept the common view in Thailand that diversified dry season cropping with irrigation is impeded by lack of markets. It is more likely that possible upland crops cannot be grown profitably under irrigation, given the production environment and alternate sources of the crops. There is very little scope for irrigated maize, for example, because it is already grown at very competitive prices in rainfed areas between the Central Plain and the Northeast. Higher yields are possible with dry season irrigation, but it appears that they are not high enough to justify the costs of supplying water in the ideal manner necessary for maize.

43. Profitability of upland farming is also jeopardized, at least in the short run, by the absence of guidelines on how large systems should be operated to supply water for diversified crops. Water management recommendations are usually based on potential water requirements and on-farm distribution methods which are largely irrelevant in systems which are operated without positive gate control at the outlets and without predictable intervals of irrigation followed by no irrigation.

44. In summary, the costs of adapting large scale rice irrigation systems to supplying the needs of upland crops in the dry season are high, their soils and topography do not favor upland crops, procedures for operating large systems for such crops are not yet instituted, and their markets are not developed because of the highly competitive agricultural economy in Thailand and doubtful prospects of profitable production. But diversified cropping will continue to be successful in smaller systems in the North where farmers have relatively strong influence on how water is controlled and where land is favorable, and some expansion is likely in the Northeast as well. Increased area for diversified cropping in the Central Plain will be limited to fruit and vegetable production on raised beds near Bangkok, and some expansion in sugarcane, especially in the Mae Klong project, if sugar prices increase relative to rice prices.
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Analyzes recent adjustments to China's agricultural pricing systems and its effects on urban consumers and overall production patterns. Defines price ratios from key inputs and outputs and examines price/cost relations in view of the institutional setting for price policy.


Agricultural Research

Points out that developing countries must invest more in agricultural research if they are to meet the needs of their growing populations. Notes that studies in Brazil, India, Japan, Mexico, and the United States show that agricultural research yields a rate of return that is more than two to three times greater than returns from most alternative investments and cites some of the successes of the high-yielding varieties of rice and wheat that were developed in the mid-1960s. Discusses the World Bank's plans to expand its lending for agricultural research and extension, particularly for the production of food and other commodities that are of importance to low-income consumers, small farmers, and resource poor areas.


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The Johns Hopkins University Press, 1983. 624 pages (including maps, bibliographies, index).

Building National Capacity to Develop Water Users' Associations: Experience from the Philippines
Frances F. Korten

Bureaucratic Politics and Incentives in the Management of Rural Development
Richard Heaver
Analyzes management problems in implementing rural development from a bureaucratic political standpoint. Emphasizes the need to take account of informal interests in managing programs. Suggests possible methods for assessing incentives.

The Design of Rural Development: Lessons from Africa
Uma Lele
Analyzes new ways of designing rural development projects to reach large numbers of low-income subsistence populations. The third paperback printing contains a new chapter by the author updating her findings.


Economic Analysis of Agricultural Projects
Second edition, completely revised and expanded
J. Price Gittinger
Sets out a careful and practical methodology for analyzing agricultural development projects and for using these analyses to compare proposed investments. It covers what constitutes a "project," what must be considered to identify possible agricultural projects, the life cycle of a project, the strengths and pitfalls of project analysis, and the calculations required to obtain financial and economic project accounts.
The methodology reflects the best of contemporary practice in government agencies and international development institutions concerned with investing in agriculture and is accessible to a broad readership of agricultural planners, engineers, and analysts. This revision adds a wealth of recent project data; expanded treatment of farm budgets and the efficiency prices that are willing to develop them further.

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The Common Agricultural Policy of the European Community: A Blessing or a Curse for Developing Countries?
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The Design of Organizations for Rural Development Projects: A Progress Report
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This book provides a how-to tool for the design and implementation of monitoring and evaluation systems in rural development projects. Because rural development projects are complex, they seek to benefit large numbers of people in remote rural areas, and they involve a variety of investments. The need for monitoring and evaluating them during implementation has been accepted in principle, but effective systems have not heretofore been formulated. The concepts of monitoring and evaluation are differentiated and issues that need to be considered in designing systems to monitor and evaluate specific projects are outlined, emphasizing the timeliness of the monitoring functions for effective management. Elaborates on such technical issues as selection of indicators, selection of survey methodology, data analysis, and presentation. It is directed primarily to those working with specific projects and will be useful to project appraisal teams, to designers of monitoring and evaluation systems, and to project staff who work with these systems.

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Monitoring Systems and Irrigation Management: An Experience from the Philippines
Agricultural economists, planners, and field workers will find this 1983 case study report a practical guide for designing efficient monitoring and evaluation systems for irrigation and similar projects. It illustrates the practical application of the principles covered in the 1982 publication Monitoring and Evaluation of Agriculture and Rural Development Projects. Highlights the problems as well as the successes.

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Prices, Taxes, and Subsidies in Pakistan Agriculture, 1960-1976
Carl Gotsch and Gilbert Brown


Project Evaluation in Regional Perspective: A Study of an Irrigation Project in Northwest Malaysia
Clive Bell, Peter Hazell, and Roger Slade

This innovative study develops quantitative methods for measuring the direct and indirect effects of agricultural projects on their surrounding regional and national economies. These methods are then applied to a study of the Muda irrigation project in northwest Malaysia. A linear programming model is used to analyze how a project changes the farm economy, and a social accounting matrix of the regional economy is then estimated. This provides the basis for a semi-input-output model, which is used to estimate the indirect effects of the project on its region. Thereafter, a similar methodology is used to estimate the project’s effects on key national variables, thus permitting a full social cost-benefit analysis of the project. The Johns Hopkins University Press. 1982. 336 pages (including maps and index). LC 81-48173. ISBN 0-8018-2802-3. Stock No. JH 2802. $30 hardcover.

Rethinking Artisanal Fisheries Development: Western Concepts, Asian Experiences


Rural Development

Discusses strategy designed to extend the benefits of development to the rural poor and outlines the World Bank’s plans for increasing its assistance in this sector. Sector Policy Paper. 1975. 89 pages (including 14 annexes). Stock No. BK 9036. $5 paperback.

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Rural Development in China
Dwight H. Perkins and Shahid Yusuf

Looks at China’s rural development experience as a whole since 1949. Analyzes China’s agricultural performance and traces it back to the technology and other sources that made that performance possible. Goes beyond the conventional sources of growth analysis to examine the political and organizational means that enabled the Chinese to mobilize so much labor for development purposes. Describes the successes and failures of China’s rural development policy. Helps clarify both the strengths and weaknesses of a self-reliant strategy of rural development.


Rural Financial Markets in Developing Countries
J. D. Von Pischke, Dale W. Adams, and Gordon Donald

Selected readings highlight facets of rural financial markets often neglected in discussions of agricultural credit in developing countries. Considers the performance of rural financial markets and ways to improve the quality and range of financial services for low-income farmers. Also reflects new thinking on the design, administration, evaluation, and policy framework of rural finance and credit programs in developing countries. The Johns Hopkins University Press. 1983. 430 pages. ISBN 0-8018-3074-5. Stock No. JH 3074. $32.50 hardcover.

Rural Poverty Unperceived: Problems and Remedies
Robert Chambers


Rural Projects through Urban Eyes: An Interpretation of the World Bank’s New-Style Rural Development Projects
Judith Tendler

most important determinant of overall economic growth, has been sluggish in Sub-Saharan African countries during the past two decades. This overview takes a three-pronged approach to understanding the problems of agricultural production in the 47 countries that make up the region. It outlines domestic and global constraints; summarizes price, trade, and consumption forecasts for major agricultural exports; and project trends.

Staff Working Paper No. 608. 1983. 172 pages (including more than 75 tables and charts).

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