Water Resources Evaluation for Paddy Irrigation
in Tropical Monsoon Asia
– A Case Study of the Ngamoeyeik Project, Lower Myanmar –

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SUMMARY

Background and Objectives

Irrigation Projects with reservoirs have contributed to stabilizing traditional rainfed rice and to introduction of double-rice in monsoon Asia, where rice is widely cultivated. In this region, the year is divided into two seasons depending on the hydrological conditions, a wet season and a dry one. Rice has been traditionally cultivated by monsoon rain during the wet season. However, the season for rice cultivation differs from place to place according to the local hydrological conditions. In regions where irrigation projects have been initiated, summer paddies are cultivated as a second rice crop during the dry season according to the water availability.

A traditional rice cropping season adopted in a region should be regarded as an optimum season for the farmers because of their long experience on the hydrology, or many successes and failures in rice cultivation due to the amount and timing of monsoon rain. However, it often causes such problems of periodic flood and drought damages in rice production. The unstable water supply under rainfed condition is a major problem in traditional rice cultivation, which has been addressed by the use of reservoirs and irrigation systems. In most irrigation projects, there are still problems with inundation of the rice due to the periodic high rainfall during the wet season, and water shortages due to the limited water storage in the reservoirs during the dry season.

Here, the change of the traditional rice cropping season, which would be resulted from the reservoirs' additional capability under proper operating conditions, may solve these problems. However, the reasonable and acceptable changes of the cropping season can be affected by, and are related to, the hydrological characteristics given and the water resources facilities used. It is necessary to analyze these interrelationships and influences to foster better rice production, and to evaluate these changes under a monsoon Asian climate that has distinct wet and dry seasons. The water resources management in the reservoir are affected by many factors such as the inflow pattern, storage capacity, overflow at the spillway, evaporation, and seepage losses.

In the Ngamoeyeik Irrigation Project Area just outside of Yangon City in Lower Myanmar, rainy season paddy cultivation has traditionally been performed from the

seedling in June to the harvesting in November under rainfed conditions. Summer paddies with irrigation from December to May were added after completion of the project in 1995. Both paddies are cultivated entirely in the rainy and dry periods, respectively.

Rain water is more than adequate for rainy paddy cultivation in this area. The project's rainy paddies often suffer from inundation of rain. Because the rice transplanting is performed during the high rainfall period, thus the young nurseries are sometime submerged under increased water level in the paddy fields after heavy rain. The farmers have to replant two or three times per year, especially in lower and depression areas.

Summer paddies are cultivated only by irrigation. There is no rain during the dry season, and the inflow into the reservoir is very limited, thus the project's summer paddies are also constrained by the limited water-storage in the reservoir in the dry season.

This research presents a challenge –namely, to maximize the benefits of both rainy and summer paddy cultivation using the reservoir.

Accordingly, the objectives of this research are, (1) to analyze the traditional cropping schedule, (2) to develop a new paddy cropping schedule shifted one month earlier to avoid inundation damage of the rainy paddies for the project based on the analysis of the rainfall characteristics, and (3) to discuss influences shifting the cropping season would have on water resources management and the effective use of the reservoir through a simulation of water storage in the reservoir.

Results and discussion

(a) Analysis of rainfall and runoff characteristic for paddy cropping season

These analyses were mainly based on the 76-year daily rainfall record at Yangon. Additional data on basic irrigation conditions were taken from the records in the Ngamoeyeik Irrigation Project.

The main results are discussed as follows.

(1) The region receives a stable rainfall for rice cultivation, with the annual average rainfall being 2,540 mm, and with the minimum being 2,000 mm.

(2) The farmers will not start the preparation works such as preparing nursery bed and land preparation for rainfed paddy cultivation until May 21, even if the soils are wet and soft enough to be ploughed.

(3) To understand the rainfall characteristics in the beginning season, the rainfall frequency over a 10-day period from May to July was analyzed, and the results showed that the rainfall approaches its stable stage in the last 10 days of May, and reaches the stability in June. There is a small difference in rainfall between June and July in short return years, but this difference almost disappears over the long-term period of 10 years. The maximum rainfall intensity occurs in the last 10 days of July.

(4) The interrelationship between rainfall intensity and duration was analyzed at different probabilities for the period of stable rainfall during the season from June to September. The moving total rainfall was calculated over 3 days and over 15 days from the end of May to September at probabilities of 50%, 30%, and 20%. It can be understood that the rainfall of the 3-day total is below 100 mm at each of the probabilities. Because the plant height was about 200 mm at transplanting, the plant could not be damaged from inundation by the rainfall, even in July. The rainfall height for the moving 15-day total is higher than the transplanted plant at probabilities of 30% and 20% during June to August. However, if evapotranspiration at the rate of 4 mm/d, which is the average value for June in the region, is considered, the possibility of plant inundation becomes lower in the beginning half of June.

(5) The special characteristics of rainfall in the region are that the 15-day rainfall, which can inundate nurseries, decrease as the time becomes earlier from the beginning of July to the end of May, while the short-term, 3-day rainfall remains constant over the month of June, July, and August. The decreasing ratios of the rainfall for the period are 22%, 31% and 28% at the probabilities of 20%, 30% and 50%, respectively.

(6) The calculation result of ratio of moving 3-day rainfall intensity to 15-day intensity during the period from the end of May to the end of September showed the stability and durability of the rainfall in the region.

(7) A comparison of the average monthly discharge and rainfall between June and July reveals that, even though the months have nearly identical amounts of rainfall, their discharge amounts are substantially different: the runoff ratio is 25% for June and 63% for July. This means that flooding is less probable in June after the long dry season.

Thus, by shifting the transplanting season of rainy paddies to begin at an earlier date, both flood damage and inundation damage by heavy rain on the transplanted nurseries can be avoided

(8) The frequency of rainfall deficit for land preparation water requirement shows that the soil is surely saturated at the end of June every year, which absolutely coincides with the time of start for transplanting. This means that the farmers place first priority on a secure supply of water for land preparation, thus preparing their nurseries to be planted after the end of June.

(9) According to the results of the land preparation water requirement (W) estimations, if the rainy paddy season is shifted one month earlier, W for the rainy paddies is increased from 0 mm to 31 mm as an average, while W for the summer paddies is decreased from 201 mm to 161 mm at the 10 % probability. In case of the shifting rainy paddy season only, although a small amount of water is needed to prepare the rainy paddies one month earlier, such a shift decreases the total water requirement from 201 mm to 192 mm, for the two seasons, at the 10% probability. If both seasons are simultaneously shifted earlier by one month, W for the rainy paddies increases to 95 mm while W for the summer paddies decreases to 77 mm by decreasing the total water requirement of the land preparation for both seasons from 201 mm to 172 mm at the 10% probability.

(10) It is seen that with very little supplementary water, the rice season of the rainy paddies can be shifted one month earlier, thereby avoiding inundation-related damage to the transplanted plants and crop yields.

(b) Evaluation of water resources management and the effective use of the reservoir

The water availability for the shifted and existing cropping season was discussed through a simulation analysis of water storage in the reservoir. Synthesized streamflow data were generated by the Thomas-Fiering Method, and used for this simulation. To assess the expected increase in seepage loss, a relationship between water level (WL) and seepage loss (SP) was analyzed by using the recorded discharge before dam construction and the calculated apparent inflow into the reservoir after dam construction, and its result is given as follows.

If $WL \leq 30.03$ m, $SP = 0.036WL + 0.62$, and if WL 30.03 m, $SP = 1.569WL - 45.42$.

The main results of the simulation analysis are discussed as follows.

(1) In the shifted season the reservoir has to retain an active storage of 8.97 MCM on May 31st to meet the target water requirements for the rainy paddies of the shifted season for one-third of the project service area. The irrigation requirement for the remaining two-thirds of the area is covered by inflows obtained during the earlier days.

(2) A result of the simulation showing the relationship between irrigated areas for summer paddies and remaining active water storage in the reservoir on May 31 at the non-exceedance probabilities of 10% and 20% clarifies that the shifted cropping season can remain more water than the existing one for a same irrigated area of summer paddies. With regard to the summer paddy area that can be irrigated in relation to the target storage, the shifted operation allows the areas of 15,200 ha expectedly, while the existing operation does the areas of 14,200 ha at the 10% probability. This simulation result of the 14,200 ha for summer paddy area at the probability of 10% has a good coincidence with the actual present summer paddies of 14,000 ha.

(3) The breakdown of water budget for the period of October 31 to May 30 under the irrigated area of 14,000 ha shows that a big ratio of outflow is occupied by the losses of evaporation and seepage: the efficiency of water use in the reservoir is 64% in the irrigated summer paddy for the case of the 10% probability. This high ratio of the losses can be regarded as a special characteristic of reservoirs in monsoon Asia, where paddy fields are irrigated using reservoirs under the hydrological conditions of distinct wet and dry seasons with high air temperatures.

(4) The more remaining active storage under the shifted cropping season means higher efficiency of water use. This advantage comes from fewer overflows at spillway, less irrigation requirement and less seepage loss, while the evaporation loss increases.

(5) The seepage losses decrease by 10.4% from 48.94 MCM to 43.87 MCM, and 9.8% from 49.81 MCM to 44.94 MCM in the shifted cropping season compared to the existing one during the dry season from October 31 to May 30 at the probabilities of 10% and 20%, respectively. This decrease in the seepage loss results from the earlier lowering of water level in the reservoir.

(6) The evaporation loss increases to 1.4% and 4.7% during the period at the probabilities of 10% and 20%, respectively. It takes place because more water has to be stored in the reservoir for the latter half of the season when the evaporation rate is high due to the extremely high air temperature.

(7) The advantages and disadvantages of the existing and the shifted cropping seasons by the items were evaluated from the viewpoint of water resources management. In the shifted cropping season, the advantages are given as increasing water availability, avoiding inundation in the rainy paddies, and increasing rice production. It also shows general precedence of the shifted cropping season while the harvesting of rainy paddies tends to be hard because of being shifted into the latter part of rainy season. However, the harvesting of summer paddies is better in the shifted cropping season because the existing one sometime suffers from earlier coming of rainy season. The overall advantage of the shifted cropping season is a product of the special characteristics of hydrological conditions in Lower Myanmar.

Conclusions and Recommendations

(1) Rainy paddies are traditionally cultivated with the goal of securing water for transplanting, which currently starts at the beginning of July. This results in a serious inundation problem during the intense rainfall of the rainy season.

(2) It is possible to avoid the inundation problem and expand the area of the summer paddies by shifting the cropping season one month earlier. This is because earlier transplanting results in increased plant height during the high rainfall period, while the water resources during the latter period of the rainy season can be used for preparing the summer paddies.

(3) The rainy paddy season can be shifted one month earlier without increasing the total water requirement for land preparation of summer and rainy paddies. Such a shift can significantly reduce the risk of rice plant damage due to inundation, since the plant heads will be higher and will be above the surface of the water during heavy rains.

(4) It may also be possible to shift the summer paddy season earlier with less water requirement for land preparation. However, for its realization the farmers are requested to keep water in the paddy fields after harvesting the rainy paddies in preparation for the next land preparation.

(5) The introduction of an irrigation system using reservoirs has the technical possibility of shifting the traditional cropping season, which in Lower Myanmar leads to inundation problems for young rice plants.

(6) A certain amount of water storage is required for the earlier rainy paddies, which would cause an increase in evaporation loss from the reservoir. However, the simulation of water storage in the reservoir has shown that the other factors related to the water budget, such as seepage and overflow, could compensate for this, and even increase the availability of water. It has also shown that the evaporation loss in the water budget during the dry season is as high as some 16%.

(7) In the shifted cropping season, the irrigated area for summer paddies can be expanded by 7% and 9.5% at the non-exceedance probabilities of 10% and 20% for the water resources failures, respectively.

(8) Overall evaluation by item shows the advantages of the shifted cropping season. This result is highly influenced by the special characteristics of the hydrological conditions found in tropical monsoon Asia.

(9) The process and methodology used in this research can be adoptively developed for new conditions of increased water demand and additional water resources development in the project, and elsewhere in Lower Myanmar.

ACKNOWLEDGEMENTS

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Chapter 1

Introduction

1.1 Backgrounds and Scope

Sustainable agricultural development (SAD) and integrated water resources management (IWRM) are the global issues to be fully adopted throughout the world (Bouwer, 2000, Batchelor, 1999). More and more water will be needed to meet the increasing demands for agriculture, industry, and domestic sectors and environmental control. Water availability will be a serious constraint in achieving the food supply for ever growing population.

SAD requires technologies and practices that make more efficient and productive use of resources and an enabling environment that encourages the adoption of these technologies. SAD is defined as the management and conservation of the natural resource base and orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations (Batchelor, 1999).

Concepts and definitions of IWRM have not been fully established. However, it stresses that integrated management of land and water resources at the basin or catchments level is the basis for all actions to address the water crisis (JIID, 2003a).

New institutions, new technologies, and new ways of managing water resources will be required to address problems; (1) how to allocate water for competing uses - to meet agriculture, industry, domestic and environmental needs, (2) how to integrate the management of surface and ground water resources, and (3) how to manage the systems to produce more yield. To address these issues the new concept of integrated water resources management (IWRM) must be adopted (Barker, 2000). Bouwer (2000) also pointed out that more research need to be sure that management of water and other resources is based on sound sciences and engineering.

Rice, wheat, and maize are predominate three grain-crops for food, and these are the products of agriculture sector, coming from rainfed and irrigated fields. Water

supply for these major crops is very important. Especially, water supply for irrigation should be regarded as an important role for the food security. However, the need for irrigation water is likely to be greater than currently anticipated, and the available supply of it less than anticipated.

By definition, the water requirements of rainfed crops are met by rainfall, which is supplied freely by nature and rarely counted in estimates of global agricultural water use. In a world of deepening water scarcity, rainfed land will thus become increasingly important to global food security. Clearly, greater effort are needed to raise the water productivity of the global crop base, both rainfed and irrigated (Postel, 1998).

Availability, variability, and reliability are key issues to user of water resources. Here, reservoirs are an obvious means to improve the characteristics of water resources in this regard. Consequently, reservoir development has played an important role in water resources management, and its management process can be very dynamic, reflecting the role of reservoirs in a region's economic and social life. In the future, in many regions of the world, instead of planning and designing new reservoirs, more emphasis will be placed on the management of existing reservoirs (Takeuchi et al., 1998).

Rice is widely cultivated in monsoon Asia due to favorable resources, an abundant monsoon rainfall, and land. In this region, the year is divided into two seasons depending on the hydrological conditions, a wet season and a dry one. Rice has been cultivated mostly by monsoon rain during the wet season. Even in the Asian monsoon region, however, water is not always abundant in the rainy season due to the fluctuation of unforeseen weather. Thus, with paddy field irrigation in the Asian monsoon region, the amount of irrigation water needed for crops can vary greatly, depending on the timing and amount of actual rainfall (JIID, 2003a). In regions where irrigation projects have been initiated, dry season paddies are also cultivated as a second rice crop during the dry season, using reservoirs and irrigation systems. This is a common practice in this region.

A traditional rice cropping season adopted in a region should be regarded as an optimum season for the farmers because of their long experience on the hydrology, or many successes and failures in rice cultivation due to the amount and timing of monsoon rain. It often causes such problems of flood and drought damages in rice

production. The unstable water supply under rainfed condition is a major problem in traditional rice cultivation, one that has been addressed by the use of reservoirs and irrigation systems. Irrigation projects can also increase second rice cultivation during the dry season. However, in most irrigation projects, there are still problems with inundation of the rice during the wet season, and water shortages during the dry season.

Reservoirs play a major role in modifying the uneven distribution of water both in space and time, and also make the best use of the available water under the optimal operation (Nandalal et al., 2002). Under proper operating conditions, reservoirs can solve the problem of uneven water supply and increase rice production.

As an additional function, reservoirs can allow farmers to change the traditional rice cropping season. However, the reasonable and acceptable changes of the cropping season can be affected by, and are related to, the hydrological characteristics that are present and the water resources facilities that are being used. It is necessary to analyze these interrelationships and influences to foster better rice production.

In Japan, the traditional rice transplanting season has been gradually shifted to earlier period from June to the end of April when dams and reservoirs are constructed (Satoh, 2000a). The main reasons are (1) to avoid the rice damage by typhoons in September, (2) to get stable water from rain for rice during flowering stage, (3) to get enough sunshine for rice maturing stage. In Japan, the rainfall is higher in June and July, and temperature is highest in August. Before then, the farmers could not perform land preparation and rice transplanting in earlier season due to the rainfall deficit and water shortage, thus the rice production was stressed by typhoons, rainfall deficit and temperature. These problems were addressed by dam, reservoirs, and irrigation facilities.

The rice-growing areas are mostly in the delta region of Lower Myanmar, where rainfed paddy cultivation prevails. Most of this rice is cultivated as a single crop under the favorable weather conditions of an abundant rainfall there. Generally, rain water is more than adequate for monsoon rainfed rice cultivation in Lower Myanmar. Poor water control and drainage works, however, contribute to periodic flooding and crop losses. The farmers prepare the land on the bed of paddy fields after the soil is fully saturated, and start transplanting with 30- to 40-day-old seedlings from the beginning of July during the high rainfall period. Under this condition, transplanted plants are sometimes submerged under increasing water in the paddy fields, and the farmers suffer from

inundation damage of the plants and have to replant two or three times per year, especially in the lower and depression areas.

In 1992-93, summer paddies were started (MOAI, 1996) throughout the country in conjunction with irrigation systems and flood-control projects. Since then, the cropping season of summer paddies has begun just after the traditional rainy paddy season. While summer paddies have been promoted by these projects, there continues to be an inundation problem in the rainy paddies of the region. This presents a challenge— namely, to maximize the benefits of both rainy and summer paddy cultivation using the new irrigation system and water-storage reservoirs. The main questions are considered from the following points.

(1) Now in Myanmar, what is rice planting season and what are factors deciding its period?

(2) What will be that the reasonable planting period under the new situation that have been and will be created by irrigation and flood control projects?

(3) Which is the most reasonable way to operate and manage the reservoir?

1.2 Objectives

In the Ngamoeyeik Irrigation Project Area just outside of Yangon City in Lower Myanmar, rainy season paddy cultivation has traditionally been performed from the seedling in June to the harvesting in November under rainfed conditions. Summer paddies with irrigation from December to May were added after completion of the project in 1995. Both paddies are cultivated entirely under the rainy and dry periods, respectively.

Rain water is more than adequate for rainy paddy cultivation in this area. The project's rainy paddies often suffer from inundation of rain. Because the rice transplanting is performed during the high rainfall period, the young nurseries are submerged under increased water level in the paddy fields concentrated by rain during the rainy season. The farmers have to replant two or three times per year, especially lower and depression areas.

Summer paddies are cultivated only by irrigation. There is no rain during the dry season, and the inflow into the reservoir is very limited, thus the project's summer

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paddies are also constrained by the limited water-storage in the reservoir in the dry season.

This presents a challenge –namely, to maximize the benefits of both rainy and summer paddy cultivation using the reservoir.

Accordingly, the objectives of this research are to analyze the traditional cropping schedule, and to develop a new paddy cropping schedule shifted one month earlier to avoid inundation damage of the rainy paddies for the project based on the analysis of the rainfall characteristics, and to discuss influences shifting the cropping season would have on water resources management, and the effective use of the reservoir through a simulation of water storage in the reservoir.

1.3 General Framework

Under favorable climate and hydrology, rice is widely cultivated in monsoon Asia. Traditional rainfed rice is cultivated in wet season mainly by monsoon rain. Due to a fluctuation of the rain in timing and amount, the farmers suffer from flood and drought in rainfed rice cultivation, thus the rice yield is low.

In regions where irrigation projects have been initiated, summer paddies are also cultivated as a second rice crop during the dry season, using reservoirs and irrigation systems. This is a common practice in this region.

Under a new condition, rice production could be increased in the region, the traditional rainfed rice, however, still suffers from the problems, and the summer paddy production are also controlled by the limited water during the dry season.

To solve these problems, a new operation for irrigation has been proposed through a case study of the Ngamoeyeik Irrigation Project in Lower Myanmar. A general framework of this process is presented in Fig.1.1.

A main problem there is an inundation of the transplanted plant in the traditional rainfed rice, even under the project, while summer paddies are limited by the water availability in the reservoir. Consequently, the shifted cropping season has been proposed to avoid the inundation damage in the rainy paddies and to get more water availability for the summer paddies.

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│  CLIMATE AND HYDROLOGY                        │
│  Tropical Monsoon Asian Region                │
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TRADITIONAL RAINFED RICE
Unstable water supply from rain
    - Flood and drought problems
    - Low yield

IRRIGATION DEVELOPMENT
Reservoirs, diversion structures,
and other facilities

DOUBLE-RICE CULTIVATION
Rainy paddy in the wet season
    - Periodic flood, drought, and
      inundation damages
    - Unstable yield
Summer paddy in the dry season
    - Limited water resources
    - Water shortage in irrigated rice
    - Limited irrigated area

RESERVOIR OPERATION

SHIFTING THE TRADITIONAL
CROPPING SEASON

EVALUATION OF RAINFALL CHARACTERISTICS
- Intensity, amount and timing of rainfall
- Water requirement estimation

RAINY PADDY
- Avoiding inundation damage

SUMMER PADDY
- Increasing irrigated area

SIMULATION OF THE WATER STORAGE
- Thomas-Fiering Method for stramflow synthesis
- Estimation of the evaporation and seepage losses in the reservoir
- Behavior Analysis

OVERALL EVALUATION
- Water availability
- Overall water requirement
- Seepage loss
- Evaporation loss
- Irrigated summer paddy area

PROPOSAL
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Fig. 1.1 A General Framework of the Research

First, the characteristics of rainfall there such as intensity, amount and timing, runoff condition are analyzed for shifting the cropping season. Then, under consideration of water requirement at the on-farm level, the water requirement for earlier land preparation caused by the rainfall deficit in the beginning period of the rainy season is estimated. Through this analysis, the traditional cropping season can be shifted one month earlier for both paddies that can avoid the inundation damage in the rainy paddies, and increase the irrigated area in the summer paddies.

Water availability and water resources management in the reservoir are then analyzed based on a simulation of water storage for the shifted and existing cropping seasons. The Thomas-Fiering streamflow model is applied for generating flow discharge, which is used in the simulation. For the reservoir water budget, seepage and evaporation losses are estimated. The seepage loss in the reservoir is estimated in relation to water level.

This simulation is performed from October 1st to June 30th for both existing and shifted operations. Evaporation, seepage losses, overflow at the spillway, irrigation, and water storage in the reservoir are discussed for the shifted and existing operations. The results of the simulation are discussed for the better operation of the shifted cropping season.

1.4 The Organization of the Dissertation

The background and objectives of this research have been presented in this chapter. The general framework has also been presented for better understanding of the process in this work.

The characteristics of rice production in monsoon Asia are presented in Chapter 2. Definition of monsoon Asia, its climate and hydrology, and its role in rice production in the world are introduced in this chapter.

Chapter 3 presents the research area, the Ngamoeyeik Irrigation Project, Lower Myanmar, and the characteristics of rice production in this area. The main problems of inundation and drainage in the rainy paddies are explained in the section 3.5.

Chapter 4 presents the detail explanation for the characteristics of rainfall and runoff in this area. In this chapter, the shifted cropping season for Lower Myanmar will be proposed to avoid inundation damages in the rainy paddy cultivation. In the

subsections 4.2.1 to 4.2.3, the rainfall pattern, intensity, and runoff ratio are discussed how to affect on the farmers' traditional rainy paddy cultivation, and why the inundation problem is occurred in the rainy paddies. In the subsections 4.2.4 to 4.2.5, the estimated water requirements for land preparation are discussed for shifting the traditional cropping season.

Chapter 5 presents the discussion of water availability, and water resources management in the reservoir for the proposed shifted cropping season in the chapter 4. A performance of the simulation of water storage in the reservoir is presented in this chapter. In the section 5.4, the seepage loss in the reservoir is estimated in relation to water level. In the section 5.5, the streamflow is generated using the Thomas-Fiering Model to fulfill the long data length of the flow discharge for the simulation. The performance of the simulation for water storage in the reservoir is presented in the section 5.6, and water availability in the reservoir is discussed for the shifted and existing cropping seasons in the section 5.7.

Conclusions and recommendations for the shifted cropping season for Lower Myanmar, and paddy irrigation in tropical monsoon Asia are summarized in Chapter 6.

Chapter 2

Characteristics of Rice Production in Monsoon Asia

2.1 Introduction

Rice is a major grain crop in monsoon Asia and plays an important role as a fundamental and essential food for the people in this region. In particular, almost 54% of the world's population about six billion live in this regions known as humid Asia or the Asian monsoon region, covering only about 14% of the world's land area. The majority of Asia's massive population is supported by intensive paddy rice cultivation, which originates from the warm and humid environment, and nearly 90% of the world's rice is produced in the countries of this region (Masumoto, 2003).

The most paddy fields in the world distribute in this region (JIID, 2003a). The favorable weather conditions of an abundant rainfall and high air temperature there are the major supporters for rice production. The monsoon Asian rice is cultivated mainly under rainfed and irrigated conditions. The rainfed paddy rice is cultivated by monsoon rain during the wet season, and summer paddy rice is irrigated as second rice during the dry season. Due to a fluctuation of the timing and amount of rainfall in the rainy season, however, the traditional rainfed paddies often suffer from flood and drought damages. Therefore, irrigation plays its role not only to expand double-rice production in the dry season and also to the stabilization of traditional rainfed rice in the rainy season. Thus, rice production in monsoon Asia is characterized mainly by the amount and timing of monsoon rain and irrigation. A better judgement between the actual rainfall and the amount of irrigation available in the irrigation system with respect to the crop water requirement is ever required for a highly sustainable system of rice production in monsoon Asia.

2.2 Definition of Monsoon Asia

Mushiake suggests that the Asian monsoon region should be classified as follows within the greater Asian pictures (JIID, 2003a). Namely, if the world's continental land is broadly divided into tectonic zones where orogenic movement is

active and stable zones where the geology is old, this region is physiographically composed of river basins that are influenced by tectonic zones. In terms of climate classification, meanwhile, it should be seen as a high precipitation region that has annual precipitation of more than 1,000 mm and belongs to a warm climate zone (a climate classification encompassing temperature, subtropical and tropical zones). As a classification of human activity, meanwhile, the region would include a variety of artificial contrivances such as land use focusing on paddy field rice cultivation arising from natural factors, hydro-power development, hillside erosion and sediment control measures, and flood disaster countermeasures (JIID, 2003a). Asian monsoon region could be called a virtually homogenous region in that paddy rice cultivation extends over almost the world of its area. In East and Southeast Asia, there are regions that have annual precipitation of more than 1,000 mm, under the influence of monsoons. These regions belong to temperate, subtropical or tropical zones.

This monsoon Asian region is generally taken to include Japan, the Korean peninsula, China (except the western interior, the Yellow River basin, and surrounding areas), all of Southeast Asia (the Indochina peninsula and the island nations), Nepal, Bhutan, Bangladesh, Sri Lanka, and areas east of the Deccan Plateau plus southwestern coastal regions of India. These regions shall be referred to correctively as the "Asian monsoon region" (Masumoto, 2003). This region is seen in Fig.2.1.

Monsoon Asia, furthermore, roughly defined as East Asian countries having more than 1,000 mm of annual rainfall (Fig2.1), has three distinct characteristics: (1) heavy rainfall (an average of 1,000 – 2,000 mm/year), (2) rice being the single major crop and (3) small subsistence farmers (average 1 ha/household) (Takase, 2003).

There are not too many regions of the world where there is a positive water balance of over 500 mm per year. Meanwhile, the water balance in this region (calculated by subtracting annual potential evapo-transpiration from annual precipitation) generally exceeds 500 mm. It is found that the Asian monsoon region is the largest in land area and the height in population.
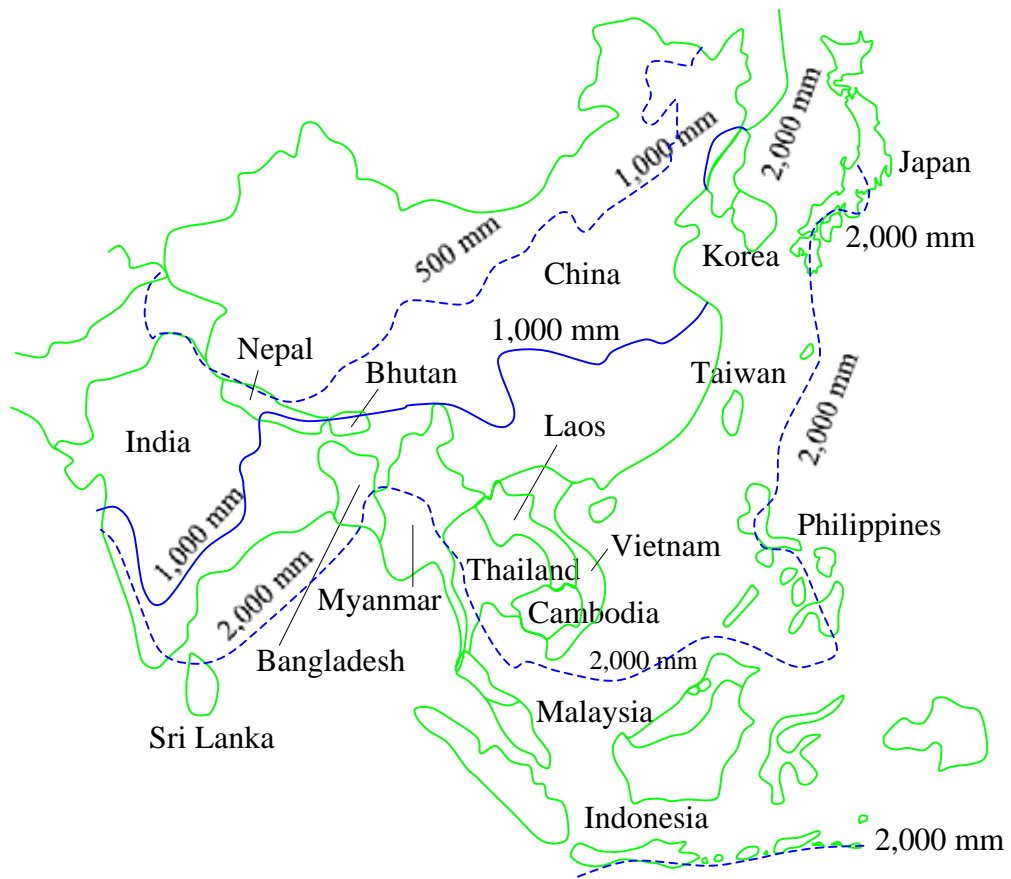
Fig.2.1 Rainfall distribution in Monsoon Asia

Source: Takase, 2003

2.3 Characteristics of Climates and Hydrology

The Asian monsoon region occupies the Indian and Pacific Oceans, and the Tibet and the Himalayan Mountain masses. Most of its consists of high-precipitation warm regions that have annual rainfall in excess of 1,500 mm, influenced by low pressure and monsoons accompanied by westerly winds. Meanwhile, the water balance generally exceeds 500 mm.

The region owns tropical and sub-tropical humid climates, and these are mainly distinct tropical wet season or tropical wet and dry season due to the hydrological conditions (Zabeltitz et al., 1999). The Asian monsoon region generally has extreme seasonal or short-term fluctuations in river flow rate, under the influence of the monsoons. It also has a relatively conspicuous tendency for flash flooding, and it contains numerous fast-flowing rivers.

The *monsoon rainy season* is very important to foster rice production in monsoon Asia. Rainfall is an essential meteorological parameter describing the monsoon climate, thus rainfall variation reflects the variability of the entire monsoon circulation system. Here, it has been recognized that a typical monsoon rainy season implies significant annual variation, an intense rainfall rate, and concentration of yearly rainfall in the local summer. Quantitative description of these characteristics requires perhaps three parameters: (1) the total amount of summer rainfall that measures the intensity of the rainy season, (2) the annual range of rainfall rate that measures the amplitude of annual variation, and (3) the seasonal distribution of rainfall that measures the ratio of summer to yearly rainfall. Thus, the domain of the monsoon rainy season is defined by rainfall characteristics (Wang et al., 2002).

The onset and withdrawal of the monsoon rainy season found in the Asian-Pacific has been studied based on the rainfall characteristics (Wang et al., 2002, Zhang et al., 2002). They found that the monsoon onset dates differ remarkably from one year to another (Table 2.1). The mean onset date is May 9th, and the season starts mostly during May. The length of the rainy season generally increases towards the equator. The longest rainy season is found in the southeast Bay of Bengal; it is about 7 months. The monsoon rainy season in Asia-Pacific region generally is divided into three groups, the Indian summer monsoon (ISM), the western North Pacific summer monsoon (WNPSM), and the east Asian summer monsoon (EASM) (Wang et al., 2002).

Table 2.1 The onset date of the Asian summer monsoon over Indochina

Year	Onset date		Year	Onset date		Year	Onset date	
1951	20	May	1967	15	Apr	1983	23	May
1952	7	May	1968	23	Apr	1984	11	May
1953	22	Apr	1969	25	May	1985	25	Apr
1954	28	Apr	1970	12	May	1986	5	May
1955	11	May	1971	2	May	1987	26	May
1956	29	Apr	1972	31	May	1988	13	Apr
1957	26	May	1973	1	May	1989	12	May
1958	13	May	1974	15	May	1990	16	May
1959	18	May	1975	2	May	1991	24	May
1960	16	May	1976	28	Apr	1992	4	Jun
1961	24	Apr	1977	4	May	1993	13	May
1962	16	May	1978	10	May	1994	5	May
1963	1	Jun	1979	17	May	1995	3	May
1964	3	May	1980	18	May	1996	22	Apr
1965	4	May	1981	1	May	Mean	9	May
1966	3	May	1982	12	May			

Source: Zhang et al., 2002

2.4. Paddy Rice Production in Monsoon Asia

Rice cultivation of paddies in the Asian monsoon region is not only an excellent form of agriculture offering high land productivity. It can be seen as a sustainable and environmentally friendly economic activity that suits the climatic and topographical conditions of the region (Masumoto, 2003).

The world rice production in 2000 was about 600 million tons (unhulled), of which 91% was produced in Asia. About 87% of the world's rice is produced in the top 10 rice-producing countries (Table 2.2), where all have annual precipitation in excess of 1,500 mm, and, of which 9 are located in Asia (JIID, 2003b).

Table 2.2 The top 10 rice producing countries in the world (2000)

Ranking	Country	Ratio to global production volume (%)	Production volume (unhulled) (mil.Tons)	Cultivation area (mil.ha)
1	China	32	190	30
2	India	22	129	45
3	Indonesia	9	52	12
4	Bangladesh	6	38	11
5	Vietnam	5	33	8
6	Thailand	4	26	10
7	Myanmar	4	21	6
8	Philippines	2	12	4
9	Japan	2	12	2
10	Brazil	87	11	4
	Subtotal	**87**	**524**	**132**
	Others	13	76	22
	Total	**100**	**600**	**154**

Source: JIID, 2003b

2.4.1 Characteristics of Paddy Rice Production in Tropical Monsoon Asia

Among the largest rice producing countries in the world, the most countries are within tropical monsoon Asia except Japan and China (Table 2.2). Tropical monsoon Asia is a region with copious rainfall, large rivers and a high population density. The rainfall and river deltas there play an important role in agricultural water supply. The four major rivers that the Ayeyarwady (Irrawaddy) River in Myanmar, the Chao Phya River in Thailand, the Red River in Vietnam, and the Mekong River are the large water resources in the Southeast Asian region, a main rice producing and exporting region, of tropical monsoon Asia. The rice production there is concentrated in these river deltas, and it is, therefore, highly influenced by the fluctuation of the rivers' water regime characterized by the monsoons (Volker, 1983).

The amount and timing of the monsoon rain are some different among the countries in the tropical Southeast Asian region (Fig.2.2). It is found that the rainfall pattern in the continent may be different from that in the peninsula and island regions. However, temperature is not a factor in rice production in these countries getting above 25 C whole year. Therefore, rice can be produced there one or more a year under distinct wet and dry seasons, if water is available.

The tropical monsoon deltas of Southeast Asia are mostly inundated for half of the year and dry for the remaining half, and thus the excessive depth of water in the rainy season and the lack of water in the dry season make somehow an effect on the rice production (Kono, 2001). Due to the fluctuation of amount and timing of the monsoon rain, farmers also often suffer from the flood and drought damages in rice cultivation, especially under rainfed condition during the rainy season. This rice is traditionally performed under the given climate and hydrology.

The rice inundation problem is found in Lower Myanmar, where the rainfed rice is mostly cultivated the outside and within the Ayeyarwady delta. Generally, rain water is more than adequate for monsoon rainfed rice cultivation there. Poor water control and drainage works cause periodic flooding and crop damages. Especially, after transplanting, the young plants are inundated under increasing water in the paddy fields that is concentrated by heavy rain during the high rainfall period.
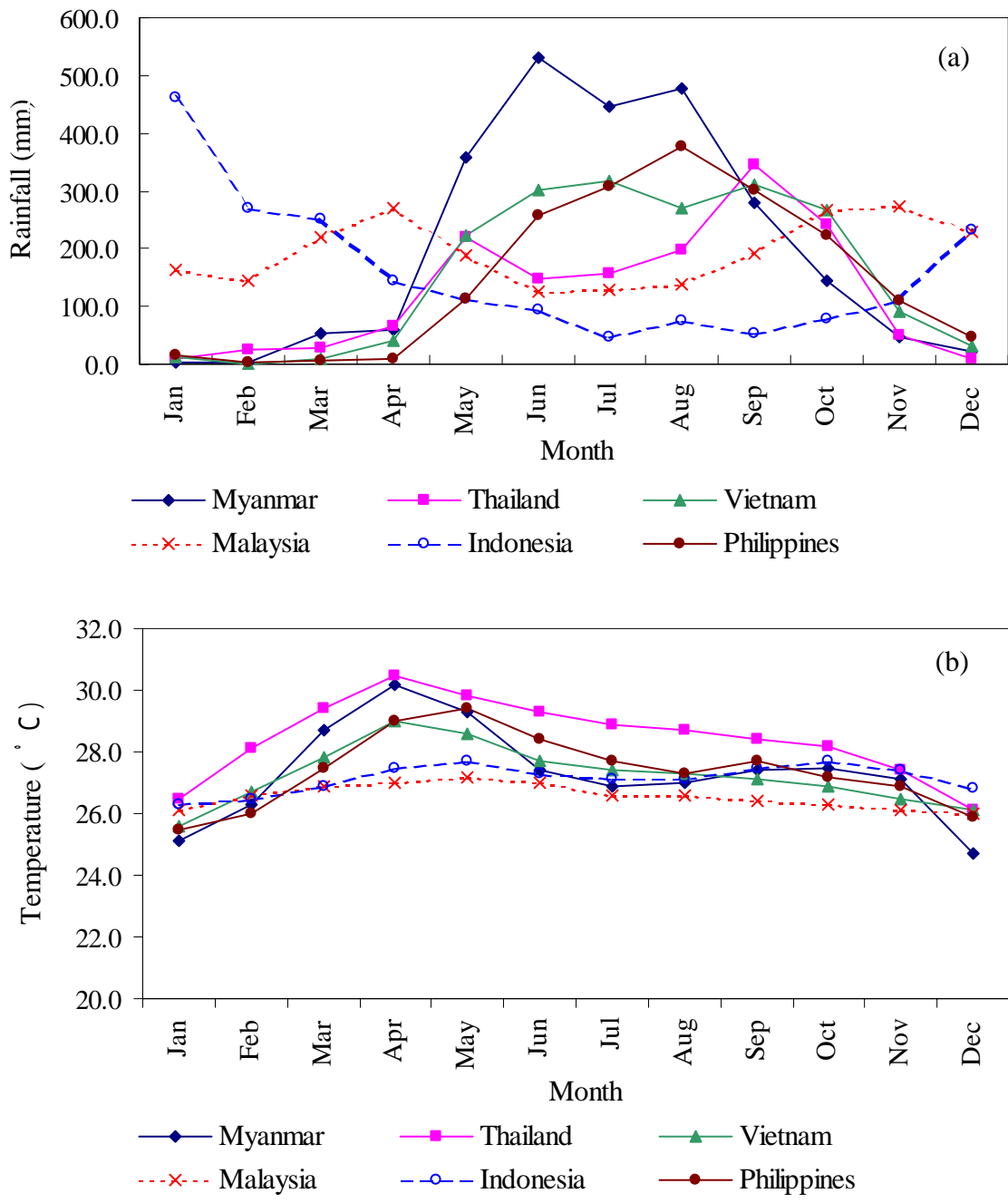
Fig.2.2 (a) average monthly rainfall, and (b) temperature in the selected Southeast

Asian countries

Remark: The data represented are for the capital of each country.

Sources: National Astronomical Observatory (NAO), 1999

The rice inundation problems are found in the Red River and the Mekong deltas in Vietnam due to poor water control and rivers flooding (Kono et al., 1995, Kono, 2001). The development of High Yielding Rice in these deltas, replacing the traditional rice is still impacted by this water regime.

2.4.2 Characteristics of Paddy Irrigation in Tropical Monsoon Asia

Irrigation can increase rice productivity to the greatest level in this region. It has contributed not only to expand summer paddies in the dry season, and also to stabilization of traditional rainfed rice in the rainy season. It is absolutely essential in the rainy season rice that the water requirement cannot always be covered by monsoon rain. Because, even in the region, unforeseen water shortages occasionally happen during the rainy season, from prolonged dry weather. The irrigation projects can also overcome to the damage of inundation and flooding in the delta rice under the proper operating condition, and improve the cropping pattern and intensity. On the other hand, even in the region, unforeseen water shortages occasionally happen during the rainy season.

The paddy field irrigation depends on collectively owned irrigation facilities such as reservoirs, dams, water supply and drainage channels, and other infrastructures set up by communities of the local farmers. It also involves water management systems for managing these facilities and distributing water by the communities. Thus, in tropical monsoon region, irrigated rice has the highest yield and productivity among the rice farming system such as irrigation, rainfed lowland, floating, and upland rice; yield is 5 t/ha, crop intensity is 2.5 crops/yr, and productivity is 12.4 t/ha/yr, while rainfed rice has 2.5 t/ha, 1 crop/yr, and 2.5 t/ha/yr, respectively (Mutert et al., 2002).

Due to the significance dependence of the economy, and society in the region on agriculture, and to the food stress for the population growth in future, more rice production is required, and irrigation remains as a major element in rice sector, contributing towards food self-sufficiency. Therefore, the better water management system in the irrigation projects, which increases the water use efficiency on the resources, is essential to foster better rice production.

2.5 Summary

Rice is a major grain crop in monsoon Asia and nearly 90% of the world's rice is produced in the countries of this region. The majority of Asia's massive population is supported by intensive paddy rice cultivation, which originates from the warm and humid environment. The rice production in monsoon Asia is characterized by the monsoon, mainly by its amount and timing of the rain. The river flooding and drought due to the fluctuation of the monsoon rain strike the farmers' rainfed rice production in the rainy season. These are addressed by irrigation projects. The double-rice production is beneficially derived from using irrigation. Irrigation remains as a major element in the rice sector, contributing towards food self-sufficiency for an ever increasing population, as well as a development of the economic and social significance in the region.

Chapter 3

Characteristics of Rice Cultivation in the Ngamoeyeik Project, Lower Myanmar

3.1 Introduction

The rice-growing areas are mostly in the delta region of Lower Myanmar, where rainfed paddy cultivation prevails. Most of this rice is cultivated as a single crop under the favorable weather conditions of an abundant rainfall there. Generally, rain water is more than adequate for monsoon rainfed rice cultivation in Lower Myanmar. To promote rice production, summer paddies were started in 1992-93 (MOAI, 1996) throughout the country in conjunction with irrigation systems and flood-control projects. Therefore, many irrigation projects have been constructed also in the rainfed paddy regions in Lower Myanmar. Since then, the cropping season of summer paddies has begun just after the traditional rainy paddy season.

3.2 Outline of the Ngamoeyeik Project

The Ngamoeyeik Project is one of the large-scale irrigation projects in Lower Myanmar. The project is situated in Hlegu Township, which is about 20-50 km northeast of Yangon City (Fig.3.1). Its main dam was constructed across Ngamoeyeik Creek, and has a length of 1.86 km, and a height of 22.9 m. The 4 saddle dams have a length of 2.87 km in total. All of the dams are made of earth. The reservoir has a gross storage capacity of 222×10^6 m^3 (MCM) with a catchment area of 414.5 km^2. The reservoir has an active storage capacity of 207 MCM and a water spread area of 44.5 km^2 when it is full. Through its two main canals, it irrigates a target area of 28,330 ha. There is a plan to supply water amounting to 0.41 MCM per day for domestic use in Yangon City. The project was completed in March, 1995. The area is bounded by creeks and rivers providing natural drainage, such as the Balar Creek, Khayein Creek and Bago River (Fig.3.2). The project' area is mostly within Hlegu Township.
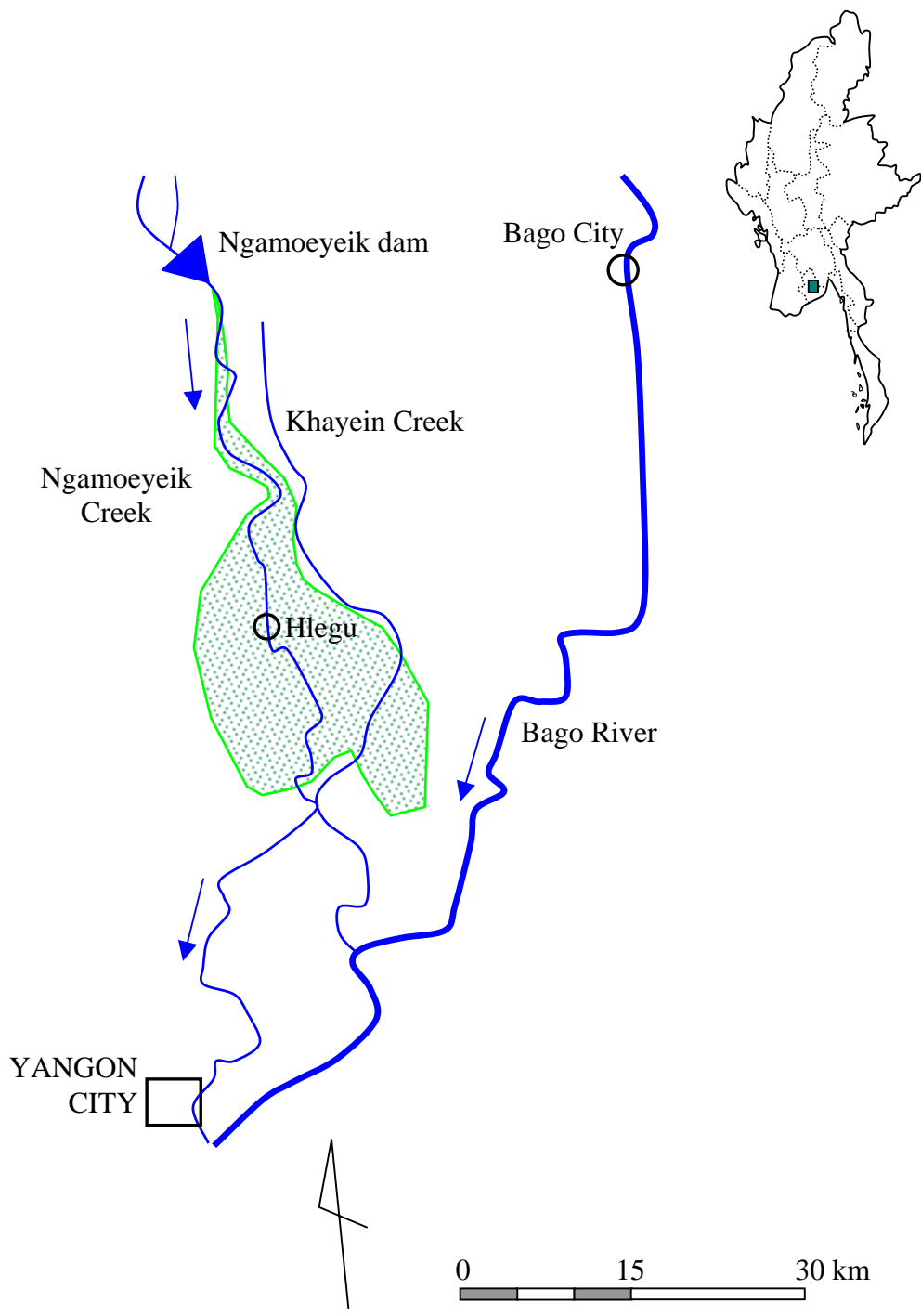
Fig.3.1 Location of the Ngamoeyeik Irrigation Project
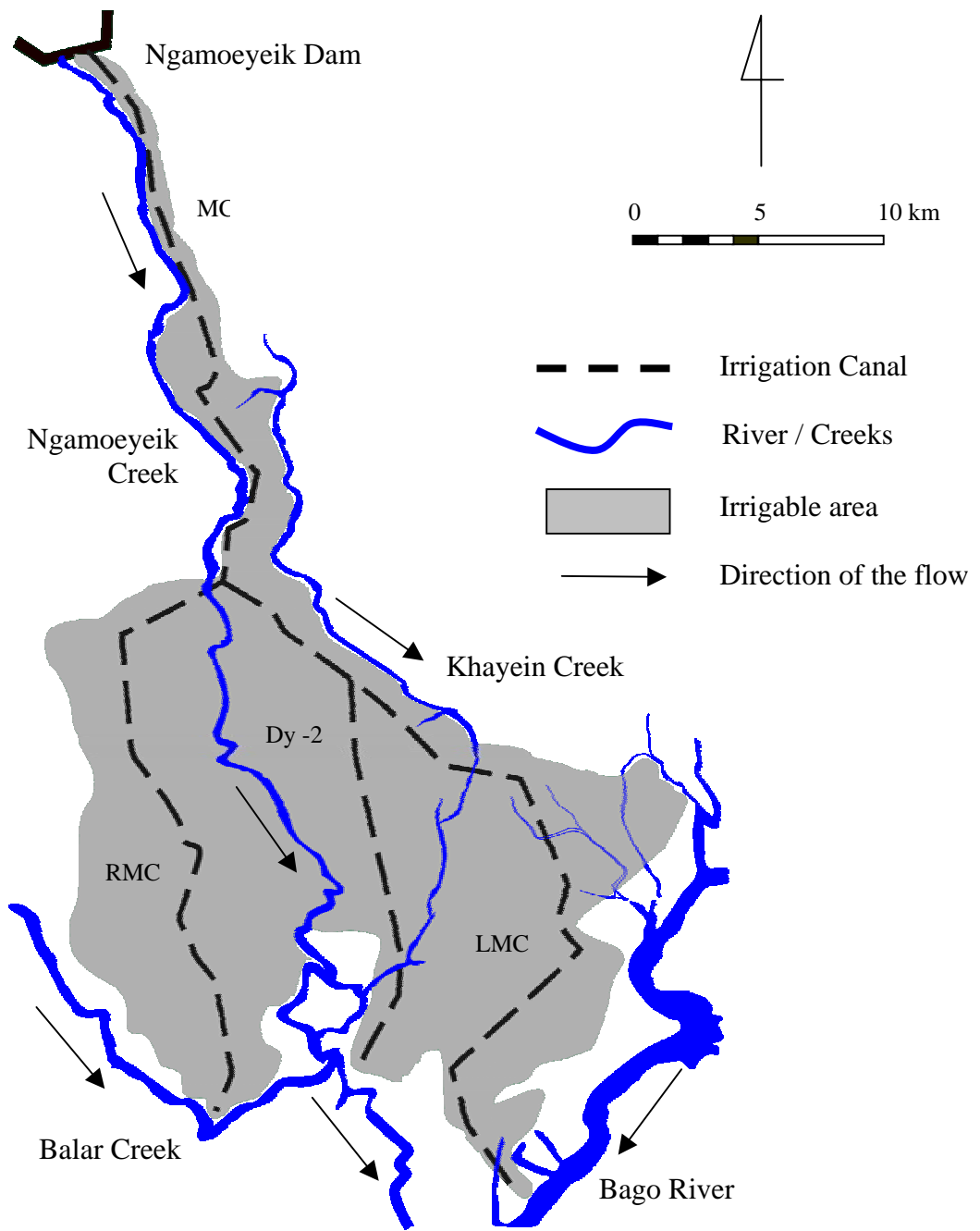
Fig.3.2 Layout of the Ngamoeyeik Irrigation Project

3.3 Climates and Hydrology

The region is warm and tropical and enjoys the southwest monsoon. The rainfall is abundant for rice cultivation. Even in drought years, the region receives a stable rainfall for rice cultivation, with the annual minimum rainfall being 2,000 mm and the annual average being 2,540 mm, of which ninety percent of the rainfall falls from May to October. This region has a rainy season and dry season in a year. The rainy season is from mid-May to mid-November, and the other half is a dry season. Rivers, rivulets, and natural drainages are flooding every year during the rainy season due to the monsoon heavy rain. However, their flow discharges are very limited during the dry season. There is almost no rain during the dry season. Daily average temperature there is above 25 C throughout a year. Thus, the region has a favorable weather environment for rice cultivation for a round-year, even in the dry season if water is available. The rainfall pattern is seen in Fig.4.2 presented in Chapter 4.

3.4 Rice Area, Cropping Pattern and Schedule

The Ngamoeyeik Irrigation Project Area is one of the largest rice production areas in Lower Myanmar. Rice is cultivated in the area twice a year, the rainy paddies from June to November and the summer paddies from December to May. The summer paddies were started in 1995 after construction of the project. The rainy paddies are totally under rainfed condition, and the summer paddies are cultivated only by irrigation using the reservoir. About 35,000 ha of rainfed rice are cultivated annually in the basin. During the last 6 years, from 1996-97 to 2001-02, an average area of 14,000 ha has been irrigated for summer paddies within the project area. The total area of irrigated summer paddies was up to about 18,500 ha, 65% of the project service area, in the year 2000. The sown rice area is seen in Fig.3.3.

The paddy area is cultivated mostly in Hlegu Township, and the area of rainy paddies occupies 95% of the total sown area in the township in 1999-2000. The summer paddies are also irrigated as large as 75% of the dry season crops. Non-paddy crops are presently found in the project area in small quantities, and comprise groundnut, sesame, maize, pulses, vegetables and small area of sunflower (Table 3.1). Among the upland crops, pulse and groundnut are mostly cultivated in the dry season.
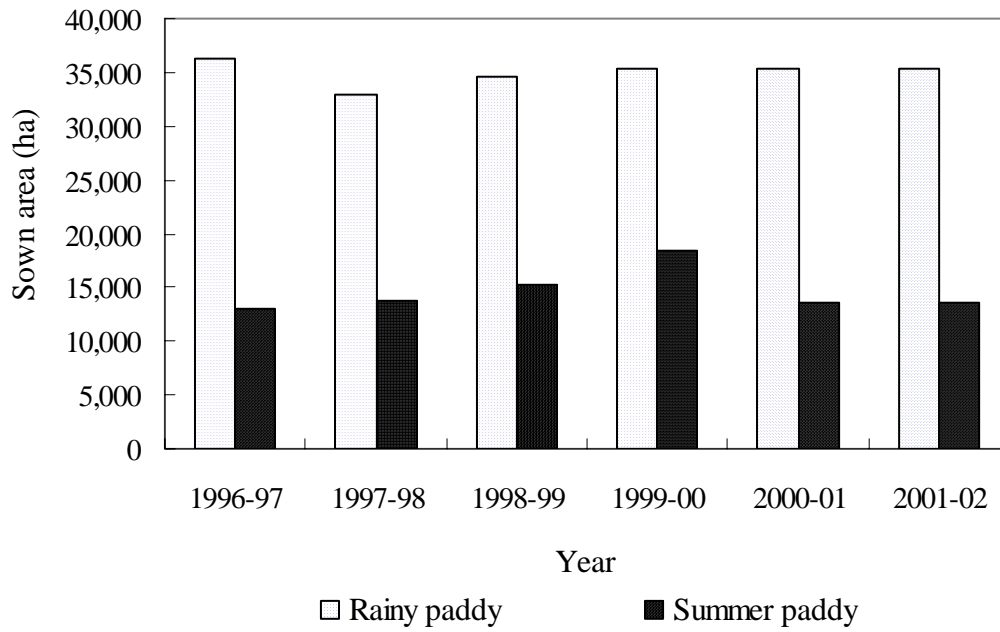
Fig.3.3 Cultivated paddy area in the Ngamoeyeik Irrigation Project

Around the outside of Yangon City, among pulses the sown area of green gram has increased dramatically in the dry season after the rainy season paddies, which follows second to irrigated summer paddies, and the farmers get a reliable benefit with the crop (Okamoto, 2000).

Table 3.1 Cropping pattern in Hlegu Township, 1999-2000

Crop	Rainy season		Dry season	
	Area (ha)	%	Area (ha)	%
Paddy	35,297	94.88	15,789	75.26
Groundnut	0	0	1,251	5.96
Sesame	490	1.32	13	0.06
Sunflower	0	0	230	1.10
Maize	0	0	12	0.06
Niger seed	250	0.67	0	0
Pulse	0	0	2,990	14.25
Vegetables	617	1.66	549	2.62
Others	546	1.47	146	0.70
Total	37,200	100	20,980	100

Source: Township Office of the Settlement and Land Records
Department, Hlegu

The project rainy paddies are still performed under the traditional rainfed paddy season as before the project. The several varieties of rice with different ages of 135-days, 125-days, 120-days, and 115-days are cultivated in the area, depending on the land and water condition. Nowadays, the farmers, however, have already adopted High Yielding Variety (HYV) rice with a short life for double rice production and requirement of increasing cropping intensity. The traditional varieties become decreasing. HYV rice with a life span of 135 days is mostly cultivated in this area. HYV rice is cultivated in

85% of the paddy fields in the area, and only small areas are cultivated with local varieties (LV), particularly in the lower and depression areas.

Figure 3.4 shows the paddy cropping schedule in the project. Transplanting is a conventional practice in the rainy paddy cultivation, and mostly takes place in July. The most paddy areas are transplanted from the beginning of July. Direct seeding with broadcasting is seen only in the small area. The farmers start harvesting in earlier transplanted areas from mid-October and then they continue it to mid-November, in some late farmers' area still at the end of November.

Summer paddies are started after harvesting the rainy paddies, from the beginning of December. Summer paddies are irrigated, broadcasted, and cultivated with HIV rice only, which is mostly a life span of 135 days.

3.5 Rainy Paddy Cultivation
3.5.1 Traditional Rainfed Rice

The several researches have been classified about rainfed rice areas in monsoon Asia. According to the classification, the rainfed lowland rice setting includes all rice-growing areas except those that are irrigated, those where water exceeds 1 m in depth, and upland area fields where water normally is not impounded. If those where water exceeds 1 m in depth, floating rice is grown. Climate, soil, water and topography are the bases for describing the rainfed rice-growing environment. The rainfed rice area is divided into shallow rainfed (5-15 cm water depth) and medium-deep rainfed (16-100 cm), and the medium-deep area is further subdivided into intermediate-deep rainfed (16-50 cm) and semi-deep rainfed (51-100 cm) (Barker, 1979). And topographically the rainfed areas also can be divided into lowland plains and river floodplain, terraces, and plateaus.

The rice area in Myanmar exists grouped into five according to water regime such as rainfed wetland, irrigated, dry land, winter and deepwater rice (U Khin Win et al., 1981). The major rice areas are along the coast and in the Ayeyarwady delta in Lower Myanmar. The most rice areas in Lower Myanmar are under rainfed.

The project area is also a main rainfed rice area in Lower Myanmar. The project rainy season paddies are still under rainfed, and very rarely require irrigation. About 35,000 ha of rainfed rice are cultivated annually in this basin.

M	J	J	A	S	O	N	D	J	F	M	A	M

N   Rainfed paddies-HYV

N   Rainfed paddies - LV

D   Summer paddies - HYV

N – Nursery (Transplanting)
D – Direct seeding

Fig.3.4 Paddy cropping schedule in Ngamoeyeik project area.

26

In the project area, The HYV rice has increased under the successful implementation of the ' Whole Township Rice Production Program' since 1977-78 (U Khin Win et al., 1981). The term HYV in Myanmar also applies to local improved varieties with high yielding potential under increased input management and low flood depths. Only small areas are cultivated with LV rice, particularly in the lower and depression areas. Fertilizer is rarely applied to HYV rice in the rainy season.

The process of rice cultivation there is the one common to the most of Southeast Asia. In land preparation, local ox-ploughs are simple, consisting of little more than a light wooden sole tipped with iron and intended to break the ground. In addition, the farmers make very extensive use of a form of a harrow with 6-8 harrowing upon which they depend for leveling the fields, puddling the wet surface at planting time and cleaning weeds. After which some farmers use blade rollers for better tilth and to reduce weeds. Large tractors are not suitable for land preparation in wetland because of soil condition, and small and irregular shape of plots. Nowadays, some farmer, however, has adopted small machines for a plough.

The farmers prepare land for a rainfed rice crop guided by their judgment of soil texture, soil moisture, and rainfall patterns, topography, and degree of weed infestation. It causes the major advantages such as improved weed control, ease of transplanting, improved soil fertility and fertilizer management, and reduced percolation losses (De Datta et al., 1978).

The farmers start their land preparation after soil is ready in completed saturation of water for ease of tillage, and the transplanting. The transplanting is sill a conventional method, and it is practiced with 30- to 40-day-old seedling. Transplanting has only so far been possible by hand; machinery transplanters are not so widely used, so that it makes a high demand on labor over the short planting period. The transplanting mostly takes place in July under high rainfall. The farmers mostly sow the seeds at elevated fields for nursery, and they normally practice the transplanting at lower fields and the broadcasting at elevated fields. If the seeding is done at lower and inundated areas, the seed cannot well germinate and yield will lessen, thus they prefer transplanting than and direct seeding with broadcasting at the inundation fields.

The farmers of the lower fields, that they suffer from water logging and inundation hire the elevated plots from the other farmers for making nursery, and they

have sometime to pay for hired fee by paddies as 10 baskets per plot (209 kg per plot). It is not fixed, and changes depending on a condition. In the inundated areas, the farmers prepare the nursery more than the requirement, for replanting at the damage areas of transplanted seedling due to flooding and inundation by heavy rain.   In the area, some farmers have practiced dry seeding for nursery, and they broadcast the seeds before rain. According to their experience, if they perform this process after rain, the seeds cannot well germinate.

3.5.2 Water Control and Diversion Condition

During the cropping season, the farmers use bunds to control and keep water in the paddy plots, and they use a simple plot-to-plot system for a release and diversion of the surplus water (Fig.3.5). The system is a common practice in Myanmar' rice cultivation. Due to the excess rainfall in this region during the rainy season, the farmers at upper and elevated plots always release and divert water to avoid rice submerge, thus the lower plots and depression areas are under too much water, and these plots are inundated in rainy season (Fig.3.6). No proper drainage system exists in the project, and the rivers, rivulets and streams are used as natural drainages. The farmers with their lands connecting each other, therefore, cooperate for water control and diversion.

3.5.3 Inundation and Drainage Problems

Rice is subjected to excessive water logging and flash-flooding on large areas in Southeast Asia, and yield performance of flood-prone rice is largely dependent on rainfall and flooding pattern, particularly in the early part of the growing season, because the early submergence, which is more critical for crop establishment, causes a greater reduction in yield (Sharma et al., 1999). The seedlings are weak and establish poorly when transplanted under excess water condition, thus the yield of transplanted rice depends more on the vigour of seedling (height and dry weight) and water regime during or after transplanting (Sharma, 1995).

In their study on rice crops in Bangladesh, Nishiyama et al. (1995) observed that rice submerged for a short period of time can survive, but rice submerged for more than a week begins to die. In cases in which flooding remains over the fields for 2-4 weeks, the time for replanting of rice is over by the time the water recedes, and thus the farmers

~   Cultivator's ownership boundary line

→   Water flow direction
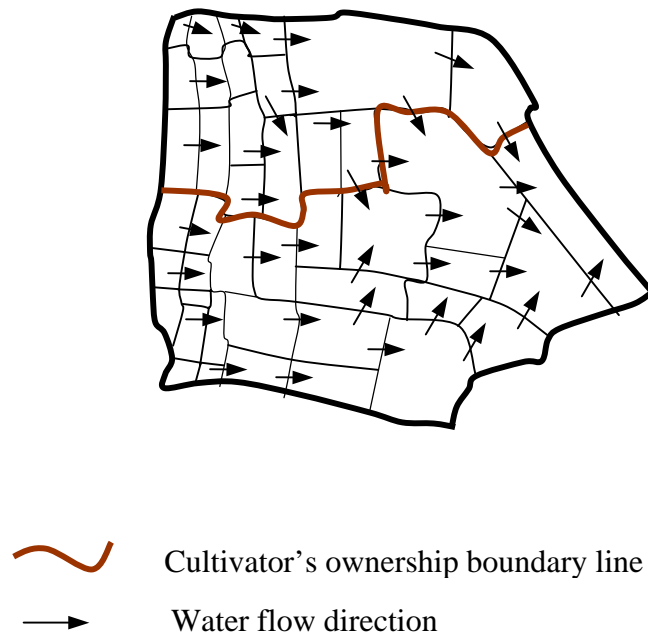
Fig.3.5 Plot-to-Plot water diversion system in two cultivators' area

(a) Rainy season: Inundation in lower plots

(b) Dry season: Too much water stored in upper plots
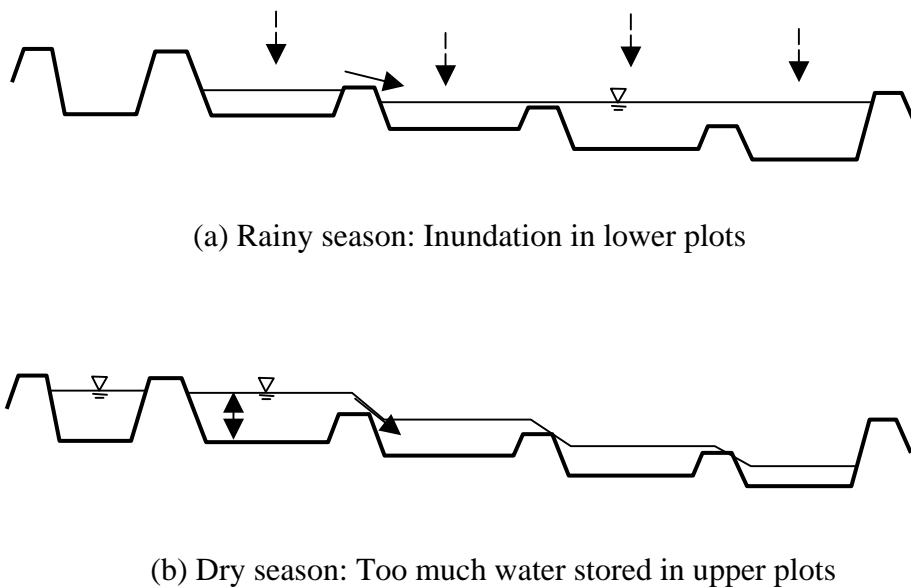
Fig.3.6 Water storage condition in paddy field in Lower Myanmar

Sources: Satoh (2000b).

derive no seasonal harvest from their cultivated land. In addition, the ponding water depth also has a profound effect on both crop growth and grain loss, with excessive ponding resulting in significantly greater losses than deficient ponding (Anbumozhi et al., 1998). De Datta (1981) similarly reported that extremely deep water resulted in poor growth and yield. Yamasaki (1992) pointed out that the damage resulting from flood water levels higher than the heads of rice plants is greater than that when the flood waters are below the rice heads.

In saline water regions, the effects of both salinity and water depth are also significant on plant growth and yield, and thus reductions in seedling establishment and grain yield results from increases of salinity and water depth (Zeng et al., 2003), and they suggest that water depth should be kept lower during the initiation and growth of productive tillers, because generally, seedling establishment and grain yield are better in shallow (i.e. <10 cm) water than in deep (i.e. >10 cm) water.

The major problems with the cultivation of rainfed rice in the area are the improper drainage facilities and abundant rainfall during the cropping season. Each of the vast cropping areas is drained by only a single, main drainage system. The paddy fields near natural streams or rivers can be benefited by the drainage system. Moreover, the conventional means of controlling water distribution among adjacent farmers is by using a simple plot-by-plot system. The inundation problem in this area occurs in two ways: by flooding in the lowlands along streams and by surplus water from the heavy rain that tends to concentrate in the lower plots in a plot-to-plot system (Satoh, 2000b). As a consequence, inundation is inevitable in these areas when heavy rain and flooding occur. Such inundation has a particularly profound effect on young plants during the transplanting period. Due to the high rainfall and diversion flow from upstream and elevated areas, the inundation problem is more acute in downstream and depression areas. In addition, because HYV rice having a short life and high sensitivity to water control has already been widely adopted throughout this area, excess water in the paddy fields is still harmful to the rice plant.

As a result of heavy rain and increased water level in the paddy fields, the farmers often loss their transplanted plants and must therefore replant two or three times. In the project area, the rainfed paddy area of 2,390 ha was replanted in the damage area of flooding and inundation by heavy rain in 1997-98, and the area of 1,410 ha was under

inundation, and the area of 3,240 ha suffered to lessen the crop yield. According to their experience, the rice plants can remain alive underwater for 15 days for the first time but only 7 days for the second time. Furthermore, if the plant heads are entirely underwater, the damage will be more acute.

3.6 Summer Paddy Cultivation

3.6.1 Water Consumption for Irrigation

Summer paddies are performed from December to mid-May in the dry season, and it is started from beginning of December. The farmers start land preparation for summer paddies when irrigation water is supplied. Almost all areas are under direct seeding and high yielding varieties. Local varieties are not cultivated in summer paddies. The farmers use fertilizers and manure in summer paddy production for higher yield. Irrigated area with summer paddies in Ngamoeyeik project exists into two types, one is irrigated within irrigable area by irrigation system and other is outside, where area is irrigated by return flow from upper fields and drainages.

The storage water in the reservoir is still used only to irrigate summer paddies in the area. The inflow in the reservoir is negligibly small during the dry season. An irrigated area with summer paddies in the project was varied between 13,500 ha and
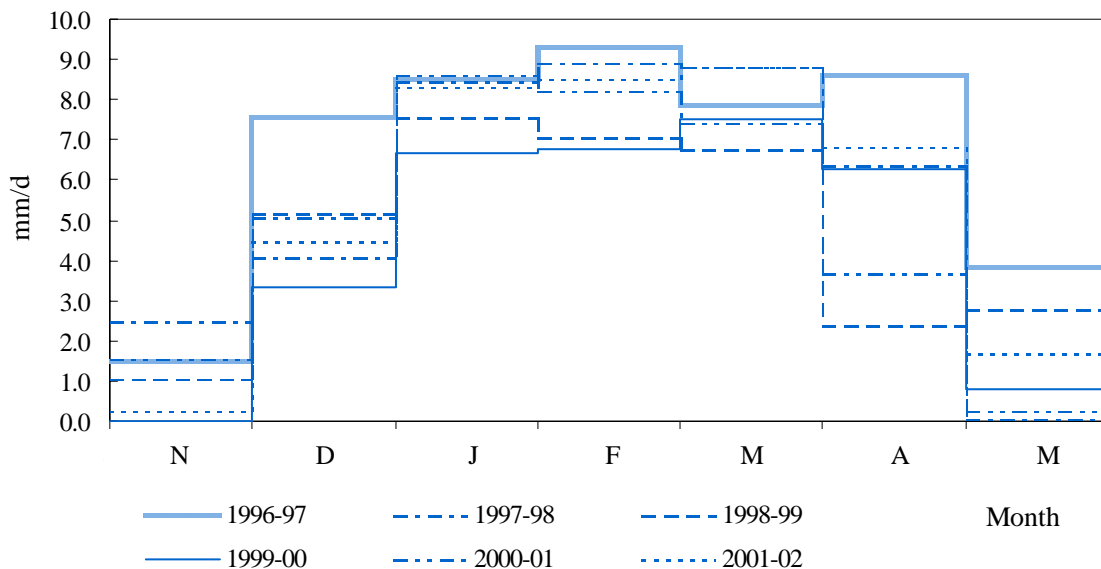
Fig.3.7 Irrigation water supply pattern for summer paddies in
the Ngamoeyeik Project

18,500 ha during the period from 1996 to 2002. A total irrigation water amount of 1,000 ~ 1,200 mm was used for summer paddies by the seasonal water supply and irrigation pattern (Fig.3.7). The storage was drawn down by irrigation until its dead storage level at the end of the season; therefore no surplus water remained in the reservoir for other purposes. The total area of irrigated summer paddies was up to about 18,500 ha, 65% of the project service area, in the year 2000. All the active water storage in the reservoir was used for the irrigation of the summer paddies, which accounted for the average water requirement rate of 8.3 mm/d for the growing season of 135 days. If the reservoir is also used to supply the domestic water needs of Yangon City, the irrigated area must be reduced.

3.6.2 Water Assessing and Distribution System

The irrigated areas are assessed water distribution mainly by a Main Canal (MC) distributed into a Right Main Canal (RMC) and a Left Main Canal (LMC) with a main distributary canal (Dy-2) (Fig.3.2). Siphon and pipe offtakes are dominant in Ngamoeyeik Irrigation Scheme. Due to insufficient irrigation supply and small water head in the canals, the farmers take water directly from main canals into their farms by using siphon and pipe offtakes, and sometime have to pump up water for irrigation. It causes the farmers lessen their intension for irrigated summer paddies and loaded by higher labor input and investment, and then lessen the summer paddy areas. To avoid water shortage problem, the farmers at upstream and canal head get much water and stores much water in their plot during the irrigation season, thus the farmers at downstream and tail portion often suffer from water shortage in their summer paddies cultivation (Fig. 3.5).

To expand summer paddy area, a temporary embankment is constructed every year at a downstream reach of Ngamoeyeik creek at the end of rainy season by the irrigation maintenance office. Return flow and drainage water are impounded in the creek by this embankment, and used for summer paddy irrigation around there. Then, reservoir supplies water into Ngamoeyeik tributary through the irrigation canals for there. The irrigation maintenance office and the farmers also construct temporary embankments across other natural streams and drainage channels, and they irrigate summer paddies and other crops by using the farmers' own pump or hired pump. The

farmers also try to assess water from return flow from upper fields and upstream areas by digging temporary small ditches for summer paddies. All temporary embankments are removed after harvesting summer paddies before monsoon rain.

3.6.3 Water Management Performance

The irrigation maintenance office has responsibilities to operate, control and maintain the main dam, main canals and distributary canals, while the minor canals, direct outlets, farm ditches and watercourse are belonged to the farmers for operation and maintenance. The irrigation maintenance office always gives the farmers guideline and instruction for equal and efficient water distribution and use.

There are some rules, that the farmers at the lower and tail areas have a priority to get water. This rule is, however, not operated well. When the water shortage problems occur during high water demand, a rotational water distribution is sometime performed at the township level.

Although Water User Groups (WUG) are established as a canal wise, to perform an effective water distribution and use, they are not also well functioned. The upstream farmers still get too much water.

3.7 Summary

After the construction of the dam and irrigation systems, double-rice production has been performed in the Ngamoeyeik project area in Lower Myanmar, rainy paddies in the rainy season, and summer paddies in the dry season. The project rainy paddies are still totally under rainfed, and it is also cultivated in the farmers' traditional cropping season as the project before. Abundant rainfall and poor drainage systems there are still a major stress in rainy paddy cultivation that the transplanted young plants often damage in inundation. This project cannot still significantly contribute to the farmers' traditional rainfed rice production.

Due to the project' water availability, summer paddies are performed, and rice production increases in this area. The irrigated summer paddy area is, however, controlled due to the limited water storage in the reservoir, and a very few inflow during the dry season. This water stress can be more acute in future, when the town water supply is started as the project's plan. On the other hand, as a dependence of the

economic, and social significance on rice production, the local farmers in this area want to increase their rice production in both paddies. Thus, the technical possibility should be considered to solve these problems.

Chapter 4

Evaluation of Rainfall Characteristics for the Paddy Cropping Schedule in Lower Myanmar

4.1 Introduction

The rice-growing areas are mostly in the delta region of Lower Myanmar, where rainfed paddy cultivation prevails. Most of this rice is cultivated as a single crop under the favorable weather conditions of an abundant rainfall there. Generally, rain water is more than adequate for monsoon rainfed rice cultivation in Lower Myanmar. Poor water control and drainage works, however, contribute to periodic flooding and crop losses. The farmers prepare the land on the bed of paddy fields after the soil is fully saturated, and start transplanting with 30- to 40-day-old seedlings from the beginning of July during the high rainfall period. Under this condition, transplanted plants are sometime submerged under increasing water in the paddy fields, and the farmers suffer from inundation damage of the plants and have to replant two or three times per year, especially in the lower and depression areas. The detail description of the rice inundation damages, and the rainfed rice performance there are presented in the previous chapter (Chapter 3).

In 1992-93, summer paddies were started (MOAI, 1996) throughout the country in conjunction with irrigation systems and flood-control projects. Since then, the cropping season of summer paddies has begun just after the traditional rainy paddy season. While summer paddies have been promoted by these projects, there continues to be an inundation problem in the rainy paddies of the region. This presents a challenge— namely, to maximize the benefits of both rainy and summer paddy cultivation using the new irrigation system and water-storage reservoirs.

Accordingly, the objectives of this research were to analyze the cropping schedule of traditional rainfed rice, and to develop a new cropping schedule to avoid inundation damage without any burden on the water-resources system. These analyses are mainly based on the 76-year daily rainfall record at Yangon. Additional data on

basic irrigation conditions were taken from the records in the Ngamoeyeik Irrigation Project.

4.2 Evaluation of Rainfall Characteristics

4.2.1 General Rainfall Pattern

Wade et al. (1999) pointed out that rainfall is an important determinant of the yield of rainfed lowland rice, and provided a review of the work on physical environment and cultivar requirements in rainfed low land rice. However, they did not include any research on rainfall reliabilities for the determination of cropping season. In the present work, the rainfall data from the 76-year records at Yangon—i.e., 1913-1999, including two periods, 1931-1932 and 1938-1946, for which there was a lack of data— were analyzed in relation to the problems of irrigation (water shortage) and drainage (inundation damage) in rice cultivation. The area is warm and tropical and enjoys the southwest monsoon. The annual rainfall changes from a year to another, however, even in drought years, the region receives a stable rainfall for rice cultivation, with the annual minimum rainfall being 2,000 mm and the annual average being 2,540 mm (Fig.4.1). Ninety percent of the annual rainfall falls from May to October, and the rainfall reaches its peak in July and August (Fig.4.2). Temperature is not a factor for the rice production in this region. The daily average temperature is above 25   C, and it allows rice growth, and cannot affect on rice production.

4.2.2 Rainfall and Runoff Characteristics

The small rain falls from the end of April and it accumulates gradually in the area. The farmers will not start the preparation works such as preparing nursery bed and land preparation for rainfed paddy cultivation until May 21, even if the soils are wet and soft enough to be ploughed. It was speculated that the rainfall distribution at the beginning of the monsoon season would be closely related to the farmers' traditional rainfed paddy season. Thus, to understand the rainfall characteristics at the beginning season, the rainfall frequency over a 10-day period from May to July was analyzed. The resulting frequency was plotted against the cumulative frequency at 50-mm intervals (Fig.4.3).
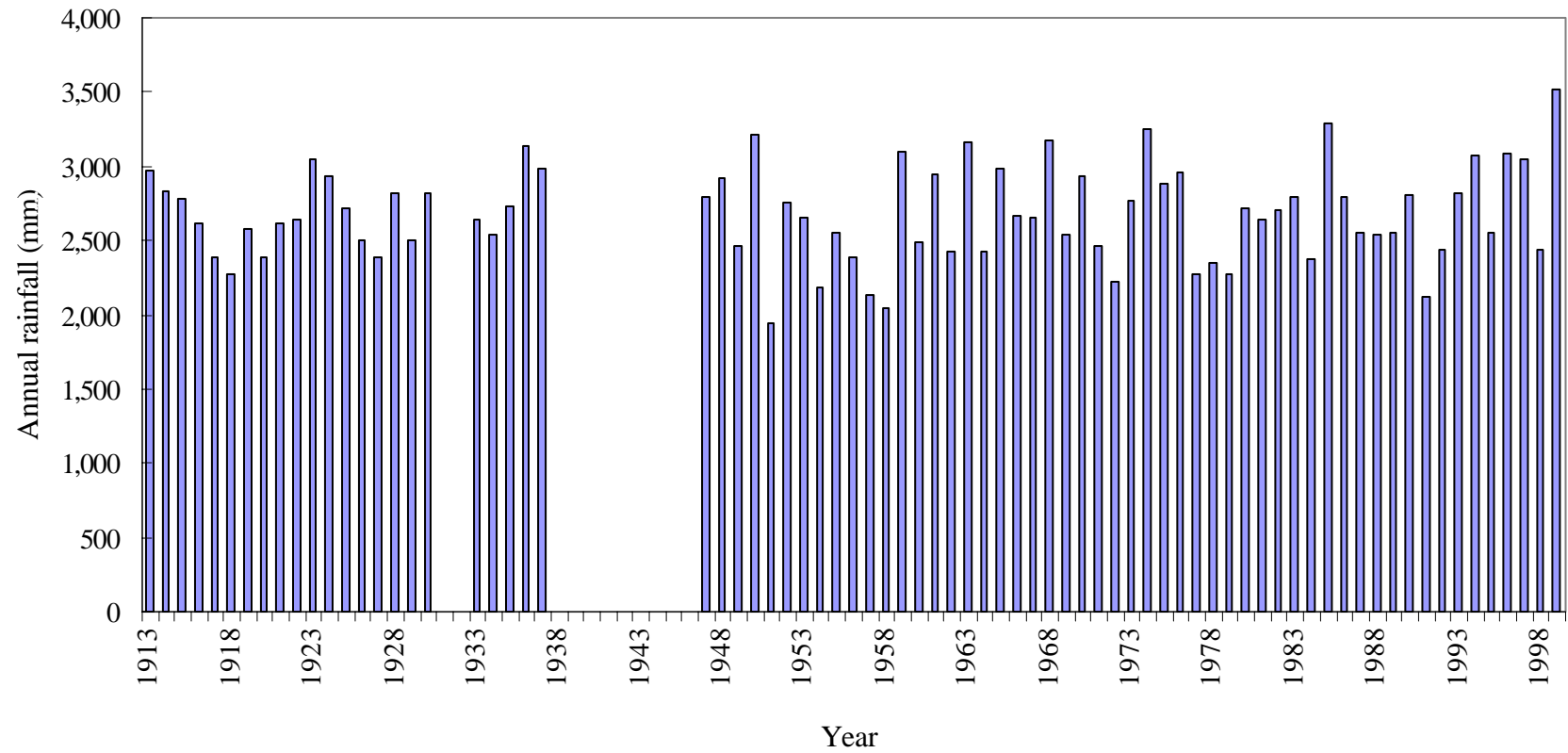
Fig.4.1 Annual rainfall, Yangon (Kaba-aye station), 1913-1999

Missing data – 1931, 32 and 1938 –1946

Source: The Department of Meteorology and Hydrology, Yangon (Kaba-aye station)
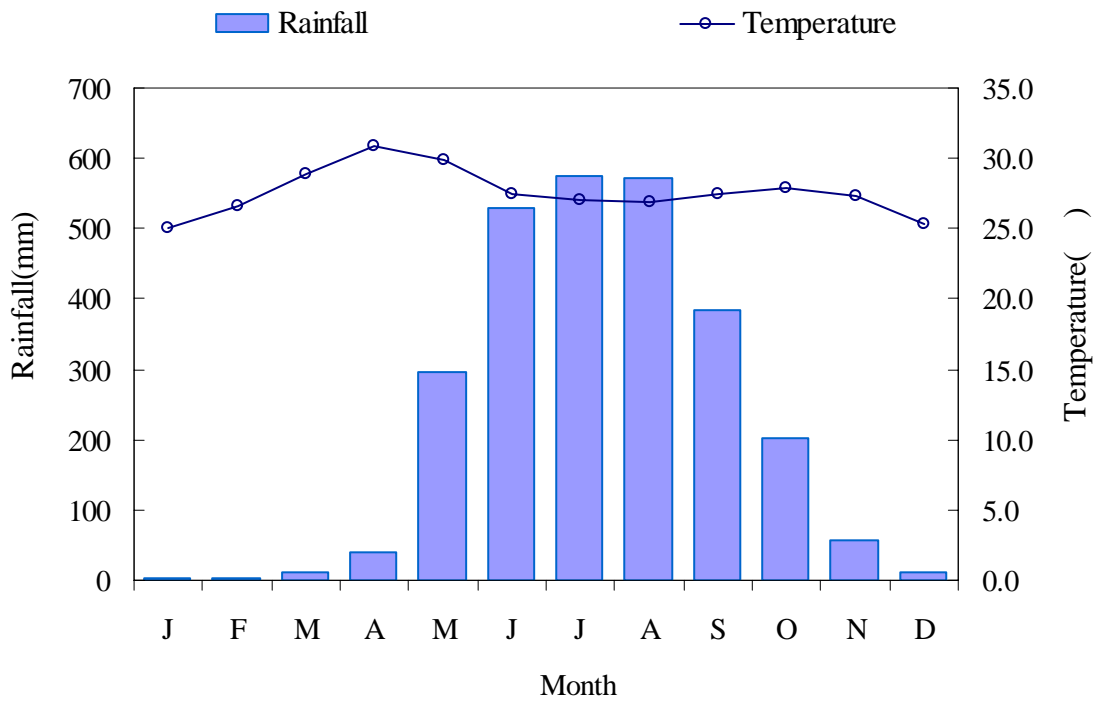
Fig.4.2 Average monthly rainfall (1913-1999) and temperature (1979-1998), Yangon

Source: The Department of Meteorology and Hydrology, Yangon (Kaba-aye station)
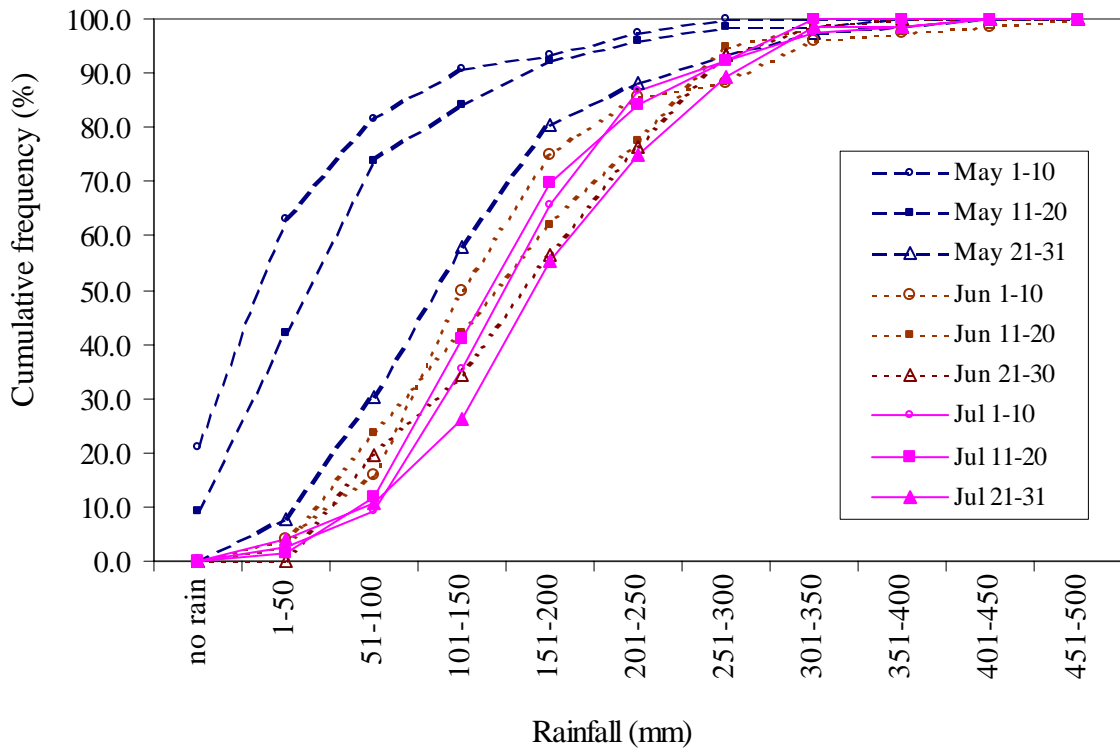
Fig.4.3 Cumulative frequency of 10-day rainfall, Yangon, 1913-1999

The results showed that the rainfall approaches its stable stage in the last 10 days of May, and reaches stability in June. There is a small difference in rainfall between June and July in short return years, but this difference almost disappears over the long-term period of 10 years. The maximum rainfall intensity occurs in the last 10 days of July during the period.

The interrelationship between rainfall intensity and duration was analyzed based on different probabilities for the period of stable rainfall during the season from June to September. The probability value was calculated by the formula

$$p = m/(n+1) \times 100, \tag{4.1}$$

where p is the exceedance probability (%), m is the ranked position with decreasing order of magnitude, and n is the number of events. The moving total rainfall was calculated over 3 days and over 15 days from the end of May to September at probabilities of 50%, 30%, and 20%, and the results are shown in Fig.4.4, in which each calculated value was placed on the last day of the duration. It can be seen that the rainfall of the 3-day total is below 100 mm at each of the probabilities. Because the plant height was about 200 mm at transplanting, the plant could not be damaged from inundation at the rainfall, even in July.

The rainfall height for the moving 15-day total is higher than the transplanted plant at probabilities of 30% and 20% during June to August. However, if evapotranspiration at the rate of 4 mm/d, which is the average value for June in the region, is considered, the possibility of plant inundation becomes lower in the beginning half of June.

The special characteristics of rainfall in the region are that the 15-day rainfall, which can inundate nurseries, decrease as the time becomes earlier from the beginning of July to the end of May, while the short-term, 3-day rainfall remains constant over the month of June, July, and August. The decreasing ratios of the rainfall for the period are 22%, 31% and 28% at probabilities of 20%, 30% and 50%, respectively.

The ratio of moving 3-day rainfall intensity to 15-day intensity during the end of May to the end of September was analyzed, and its result is shown in Fig.4.5.

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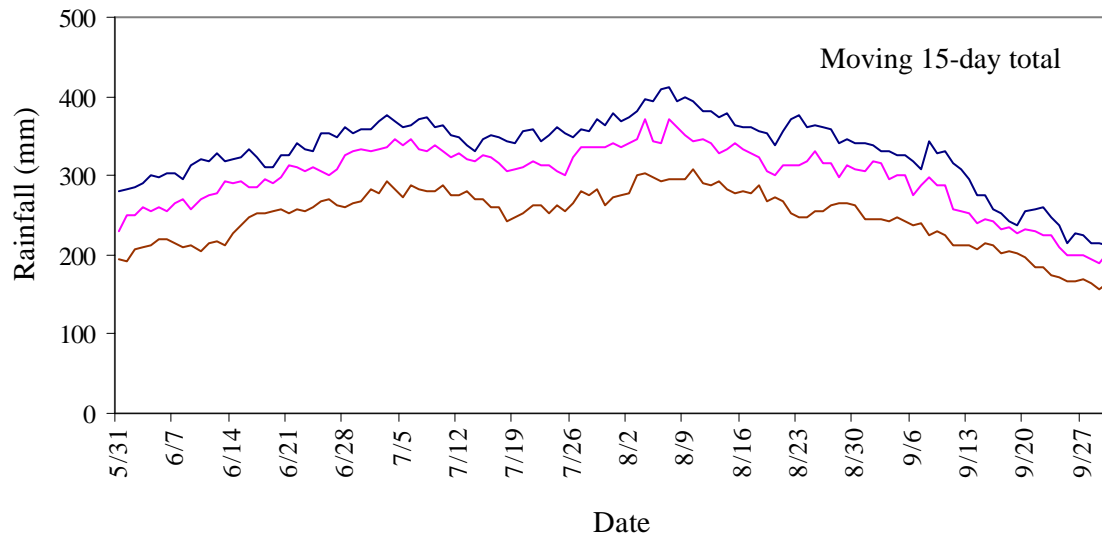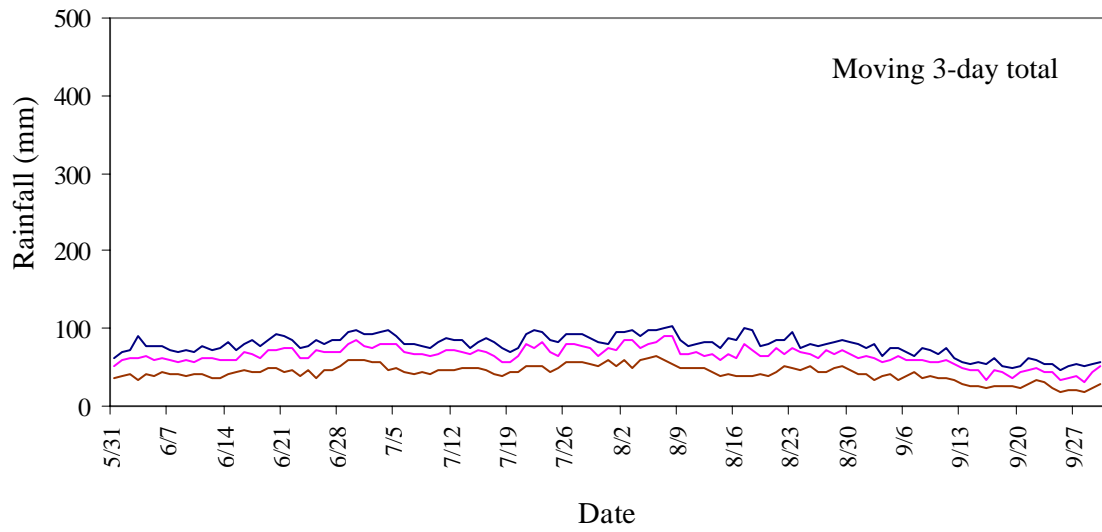
Top line ---------------- $p = 20\%$
Middle line ------------- $p = 30\%$
Bottom line ------------- $p = 50\%$

Fig.4.4 Moving 3-day and 15-day rainfall at several exceedance probabilities in the
   rainy season, Yangon, 1913-1999
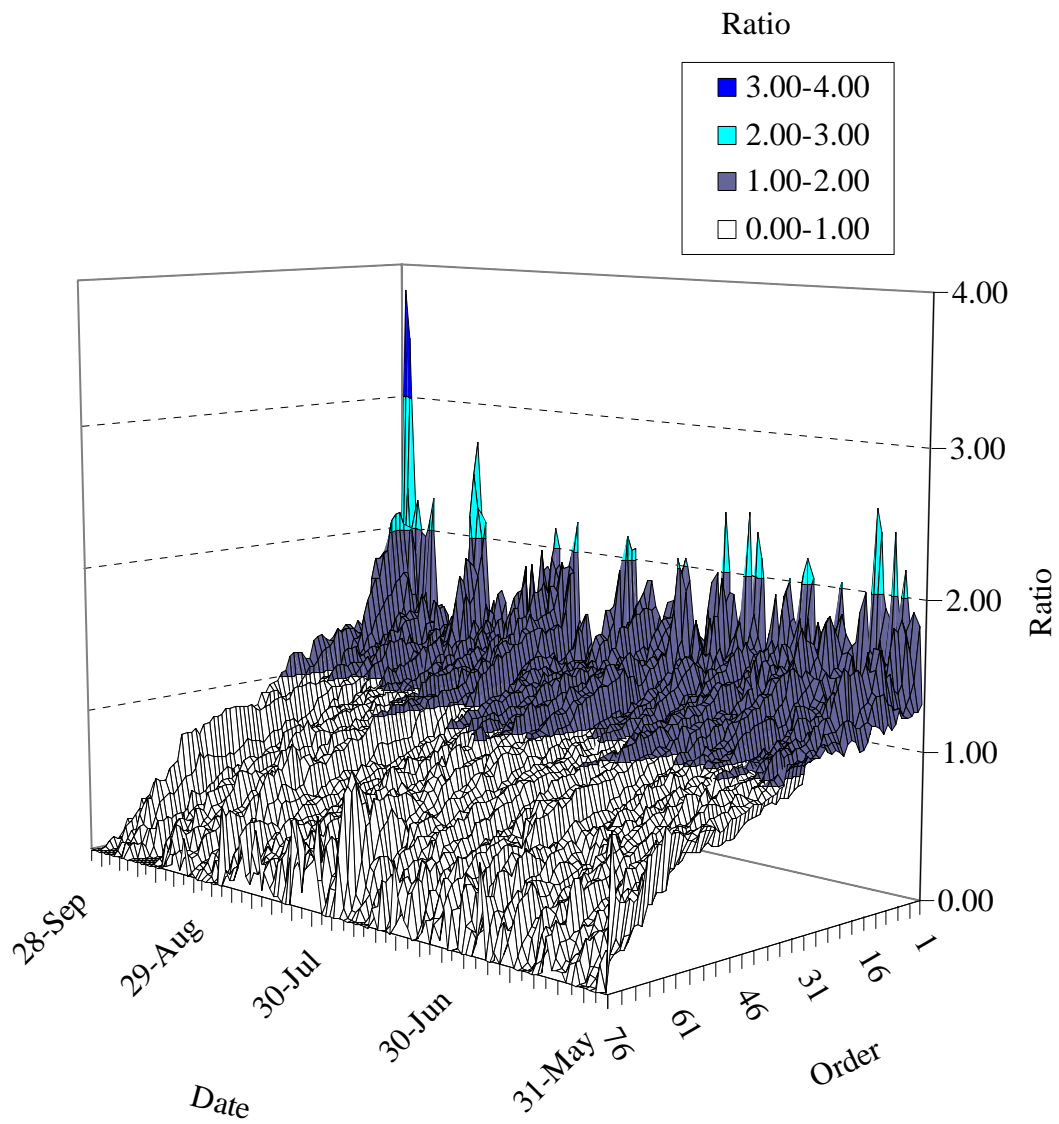
Fig.4.5 Ratio of moving 3-day rainfall intensity to 15-day intensity
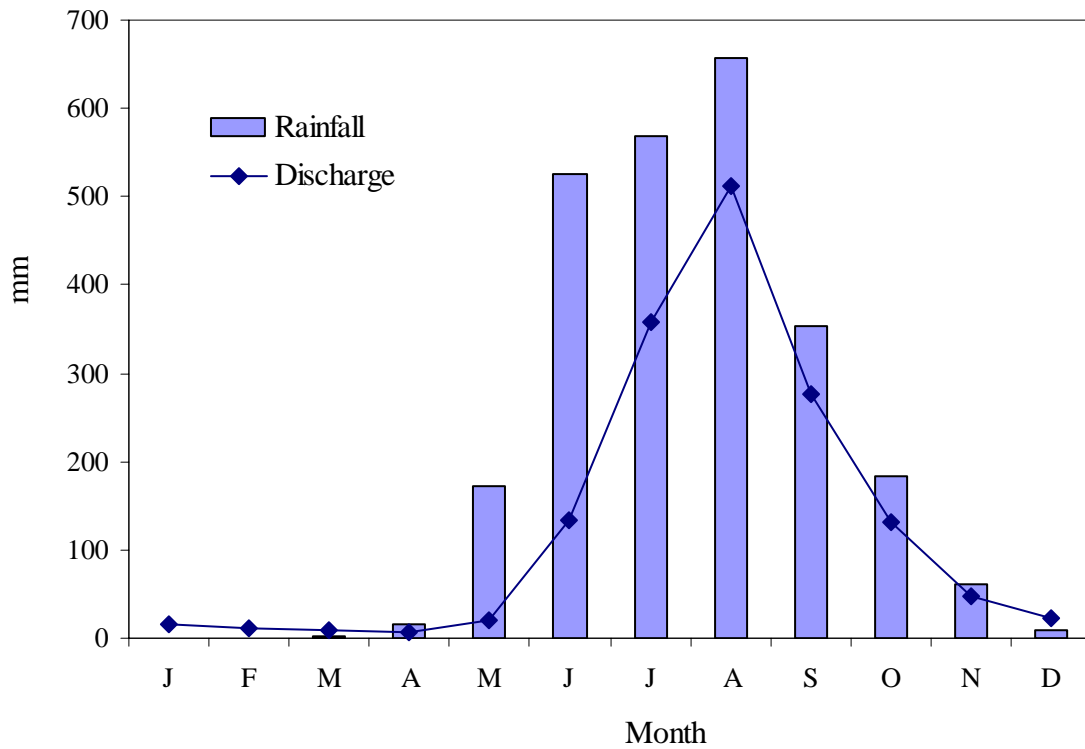
Fig.4.6 Average monthly rainfall at the dam site and discharge in the Ngamoeyeik
    Creek, Kyawzawsu station, Hlegu Township, 1982-1992

Source: The Hydrology Branch (Head Office) of the Irrigation Department, Yangon

It shows that even at first order the 3-day rainfall intensity is only about 1.5 times the 15-day rainfall intensity for most days during the period. At the 50% of the order, the 3-day intensity is still larger than the 15-day intensity for 17% of the days during this period. This shows the stability and durability of the rainfall in the region.

The average monthly discharge in the Ngamoeyeik creek, and the average monthly rainfall on the catchment area are presented in Fig.4.6. A comparison of these values reveals that, even though the months of June and July have nearly identical amounts of rainfall, their discharge amounts are substantially different: the runoff ratio is 25% for June and 63% for July. This means that flooding is less probable in June, which is just after the long dry season. Thus, by shifting the transplanting season of rainy paddies to begin at an earlier date, both flood damage and inundation damage by heavy rain on the transplanted nurseries can be avoided.

4.2.3 Rainfall Security for Land Preparation

The excessive amount of water often used in land preparation. The long period of land preparation would lead to the more water demand. Typical wetland preparation for rice culture involves supplying adequate amounts of water to saturate the soil (lank soaking) and to maintain a wet soil condition that facilitates plowing, harrowing, puddling, and land leveling so that rice seedling can be easily transplanted. Usually tillage for rain-fed rice is performed either when soil water is nearly saturated or saturated for wetland tillage (De Datta et al., 1978). But rice paddies require saturated soil for transplanting and potential growth (Wade et al., 1999).

The actual amount of water used by farmers for land preparation is often several times higher than the typical requirement of 150-250 mm (Guerra et al., 1998, Bouman et al., 2001). As Taiwan experience, approximately 120 to 200 mm of water is required for land preparation in paddy rice production (Kan et al., 1997). Shiozawa et al. (2002) points out that the puddling requirement in the clay soil of lowland paddy field in Japan is independent on the size of the field plot, and the total water amount of 240 mm is required for land preparation.

As shown in Fig.4.7, in the year 2000 in the Hlegu Township, the farmers started rainy paddy cultivation in small elevated areas by broadcasting from June 15, but most of the areas were transplanted from June 29 until August 3.
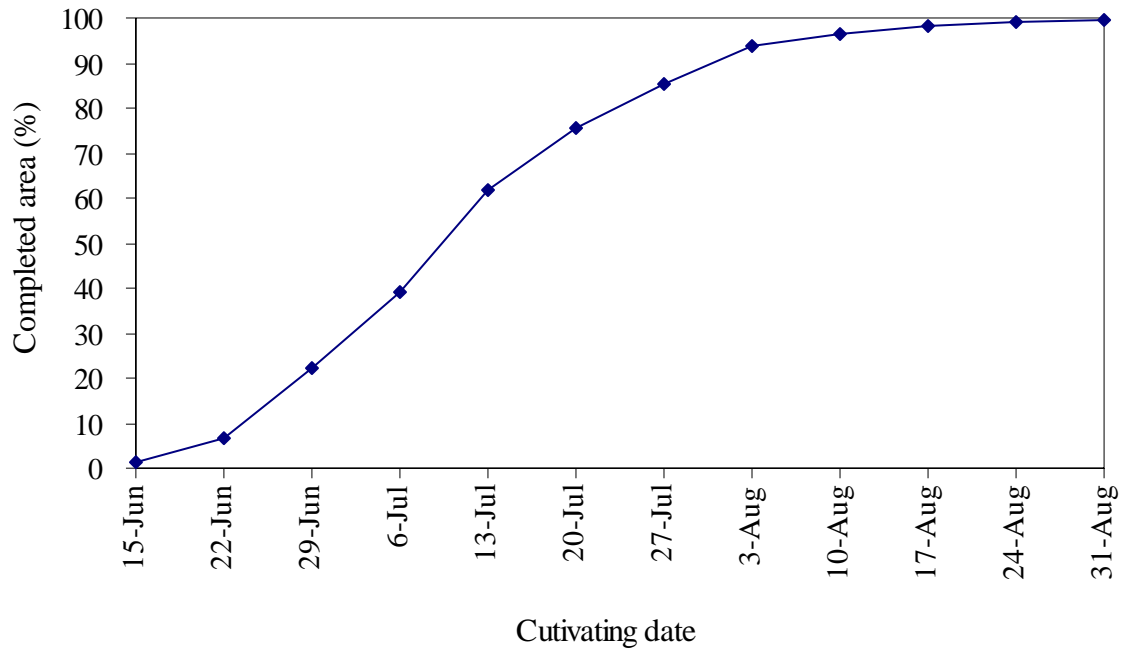
Fig.4.7 Cultivation rate of rainy paddies in Hlegu Township in 2000

Source: Township Office of the Settlement and Land Records Department, Hlegu
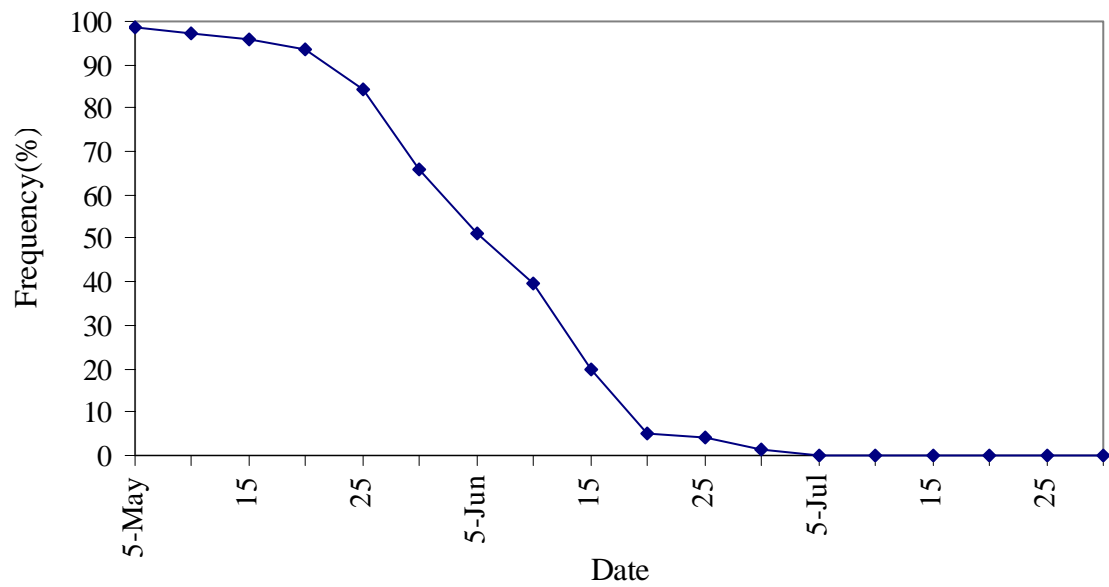
Fig.4.8 Frequency of rainfall deficit under the total water requirement for land

  preparation and evapotranspiration, Yangon, 1913-1999

To analyze the relationship between the cropping schedule and the rainfall availability, the frequency of rainfall deficit for land preparation water requirement was calculated from the beginning of May, when the soil begins to receive some moisture from small early rains, and when the process of evapotranspitration (*ET*) begins. The rainfall deficit, *D*, for a land preparation water requirement of 203 mm, which is the average design value, was calculated for each 5-day period using the equation

$$D = 203 \quad (RF \quad ET), \tag{4.2}$$

where *RF* is 5-day rainfall and *ET* is 5-day evapotranspiration. *ET* was taken as 5 mm/d for May and 4 mm/d for each of June and July according to monthly averages estimated by the Penman method. A negative value of *D* indicates that the water requirement is zero. The frequency of a deficit in rainfall to a level below the water requirement was calculated over a period of 76 years, and it was plotted against time (Fig.4.8).

The results show that the soil is surely saturated at the end of June each year, which absolutely coincides with the time of start for transplanting. This means that the farmers place first priority on a secure supply of water for land preparation, thus preparing their nurseries to be planted after the end of June.

4.2.4 Estimation of the Land Preparation Water Requirement for a Shifted Cropping Season

Shifting the cropping season to an earlier start date is proved to be effective to reduce the damage from flooding and heavy rain on the fields. However, in order to ensure a secure supply of rain for transplanting, the farmers were forced to delay the start date until the beginning of July. Now that a reservoir has been constructed, it may be possible to break this constraint. But the feasibility of an earlier start date is also dependent on the rainfall characteristics in the region.

To analyze these characteristics, the land preparation water requirement was estimated under the following conditions:

(1) The rice growing season is 135 days for both the rainy and summer seasons.
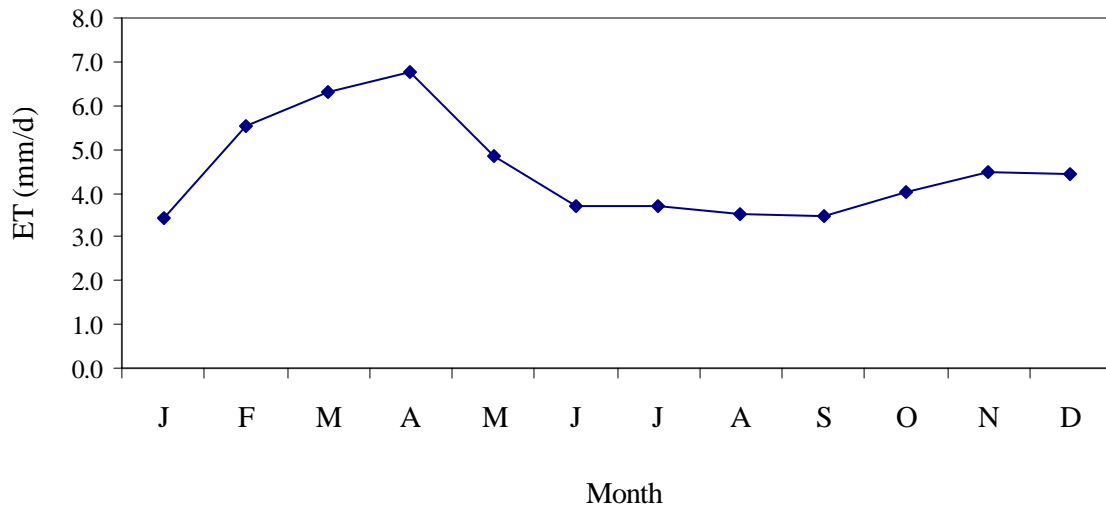
Fig.4.9 Average daily evapotranspiration, Yangon

Source: Khin Maung Nyunt (1998), Irrigation Department, Yangon

(2) The surface water is drained for harvesting after the maturation stage of rice for 15 days.

(3) The soil moisture as well as the rainfall after harvesting is carried over to the next season.

(4) The land preparation water requirement is 203 mm, which is the average design value applied by the Irrigation Department of Myanmar (Ohn Myint et al., 1987; Khin Maung Nyunt, 1998). Rainfall is supplied to and ET is reduced from the soil.

The soil moisture (mm), *SM*, during pre-harvest drainage was derived by the equation

$$SM_{i+1} = Min\ (SM_i + RF_i - ET_i,\ 203), \qquad\qquad (4.3)$$

where SM_i and SM_{i+1} are the soil moistures on ith and $i+1$ days, respectively, RF_i is the rainfall during ith day, and ET_i is the evaporation during ith day. Here, ET is assumed to be at ET_0, which ranges between 3.4 mm/d in January and 6.9 mm/d in April (Fig.4.9). The value of *SM* after harvesting was calculated by the equation

$$SM_{i+1} = SM_i + RF_i - ET_i. \qquad\qquad (4.4)$$

The water requirement for land preparation (mm), W, was derived by the equation

$$W = 203 - SM_0, \qquad\qquad (4.5)$$

where SM_0 is SM on the day of land preparation.

The calculation was performed for every combination of rainy and summer cropping season with a minimum fallow period of one month. The period for land preparation was considered to be one month for the whole area, and it was divided into 3 groups of 10 days. The exceedance probability of the land preparation water requirement was derived according to equation (4.1), and then the average W was calculated. The results are presented in Table 4.1(a & b), in which the value of W is placed in the top column for the summer paddy season, and in the bottom column for the rainy paddy season in each combination of the cropping seasons based on the beginning date of land preparation, at probabilities of 25% and 10%.

The data of Table 4.1(a) are filled from the data of Table 4.1.1(a-1), which are the average value of Table 4.1.1(a-2), and Table 4.1.2(a-1), which are the average value of Table 4.1.2 (a-2) at probability of 25%, respectively. The data of Table 4.1(b) are filled from the data of Table 4.1.1(b-1), which are the average value of Table 4.1.1(b-2), and Table 4.1.2(b-1), which are the average value of Table 4.1.2 (b-2) at probability of 10%, respectively.

Table 4.1.1(a-2) and Table 4.1.1 (b-2) show the land preparation water requirement for the rainy paddies according to the day of the puddling for the summer paddies. Table 4.1.1(a-1) and Table 4.1.1 (b-1) show the average values of the puddling water requirement, which are shown in Table 4.1.1(a-2) and Table 4.1.1 (b-2), respectively, for one month that starts on the day indicated in the vertical column.

Table 4.1.2(a-2) and Table 4.1.2 (b-2) show the land preparation water requirement for the summer paddies according to the day of the puddling for the rainy paddies. Table 4.1.2(a-1) and Table 4.1.2(b-1) show the average values of the puddling water requirement, which are shown in Table 4.1.2(a-2) and Table 4.1.2(b-2), respectively, for one month that starts on the day indicated in the vertical column.

Table 4.1 Estimated water requirement for land preparation

(a) (mm, 25% probability)

Summer Paddies / Rainy Paddies		Beginning date of land preparation			
		31-Oct	10-Nov	20-Nov	30-Nov
Beginning date of land preparation	21-May	27	40	52	91
		114	98	55	45
	31-May	43	82	103	120
		57	46	33	10
	10-June	84	105	150	171
		17	11	6	1
	20-June	106	145	173	191
		2	0	0	0
	30-June	102	139	179	197
		0	0	0	0

(b) (mm, 10% probability)

Summer Paddies / Rainy Paddies		Beginning date of land preparation			
		31-Oct	10-Nov	20-Nov	30-Nov
Beginning date of land preparation	21-May	39	73	93	115
		122	112	95	53
	31-May	77	99	140	161
		95	54	44	31
	10-June	110	143	167	187
		45	31	10	5
	20-June	124	161	186	195
		11	5	0	0
	30-June	115	154	190	201
		1	0	0	0

W for summer paddies
W for rainy paddies

Table 4.1.1 Estimated water requirement for land preparation (average) for rainy paddies by the beginning date of preparation

(a-1) Average for one month   (mm, 25% probability)

	(PHDD)	Beginning date of land preparation for summer paddies[*]						
		31-Oct	10-Nov	20-Nov	30-Nov	10-Dec	20-Dec	30-Dec
		28-Feb	10-Mar	20-Mar	30-Mar	9-Apr	19-Apr	29-Apr
Beginning date of land preparation for rainy paddies	21-May	114	98	55	45			
	31-May	57	46	33	10			
	10-Jun	17	11	6	1			
	20-Jun	2	0	0	0			
	30-Jun	0	0	0	0			
	10-Jul							
	20-Jul							
	30-Jul							

(a-2) Water requirement for the day

	(PHDD)	Beginning date of land preparation for summer paddies[*]						
		31-Oct	10-Nov	20-Nov	30-Nov	10-Dec	20-Dec	30-Dec
		28-Feb	10-Mar	20-Mar	30-Mar	9-Apr	19-Apr	29-Apr
Beginning date of land preparation for rainy paddies	21-May	203	203	203	203			
	31-May	203	203	188	125	66		
	10-Jun	201	138	75	12	0	0	
	20-Jun	27	0	0	0	0	0	0
	30-Jun	0	0	0	0	0	0	0
	10-Jul		0	0	0	0	0	0
	20-Jul			0	0	0	0	0
	30-Jul				0	0	0	0

[*] Pre-Harvest Drainage Date (PHDD) comes 4 months later.

Table 4.1.1 Estimated water requirement for land preparation (average) for rainy paddies by the beginning date of preparation (continued)

(b-1) Average for one month   (mm, 10% probability)

	(PHDD)	Beginning date of land preparation for summer paddies[*]						
		31-Oct	10-Nov	20-Nov	30-Nov	10-Dec	20-Dec	30-Dec
	(PHDD)	28-Feb	10-Mar	20-Mar	30-Mar	9-Apr	19-Apr	29-Apr
Beginning date of land preparation for rainy paddies	21-May	122	112	95	53			
	31-May	95	54	44	31			
	10-Jun	45	31	10	5			
	20-Jun	11	5	0	0			
	30-Jun	1	0	0	0			
	10-Jul							
	20-Jul							
	30-Jul							

(b-2) Water requirement for the day

	(PHDD)	Beginning date of land preparation for summer paddies[*]						
		31-Oct	10-Nov	20-Nov	30-Nov	10-Dec	20-Dec	30-Dec
	(PHDD)	28-Feb	10-Mar	20-Mar	30-Mar	9-Apr	19-Apr	29-Apr
Beginning date of land preparation for rainy paddies	21-May	203	203	203	203			
	31-May	203	203	203	183	115		
	10-Jun	203	182	123	61	2	0	
	20-Jun	128	65	2	0	0	0	0
	30-Jun	17	0	0	0	0	0	0
	10-Jul		0	0	0	0	0	0
	20-Jul			0	0	0	0	0
	30-Jul				0	0	0	0

[*] Pre-Harvest Drainage Date (PHDD) comes 4 months later.

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Table 4.1.2 Estimated water requirement for land preparation (average) for summer paddies by the beginning date of preparation

(a-1) Average for one month   (mm, 25% probability)

| | (PHDD) | Beginning date of land preparation for rainy paddies[*] | | | | | | | |
		21-May 19-Aug	31-May 29-Aug	10-Jun 8-Sep	20-Jun 18-Sep	30-Jun 28-Sep	10-Jul 8-Oct	20-Jul 18-Oct	30-Jul 28-Oct
	31-Oct	27	43	84	106	102			
	10-Nov	40	82	105	145	139			
Beginning date of	20-Nov	52	103	150	173	179			
land preparation for	30-Nov	91	120	171	191	197			
summer paddies	10-Dec								
	20-Dec								
	30-Dec								

(a-2) Water requirement for the day

| | (PHDD) | Beginning date of land preparation for rainy paddies[*] | | | | | | | |
		21-May 19-Aug	31-May 29-Aug	10-Jun 8-Sep	20-Jun 18-Sep	30-Jun 28-Sep	10-Jul 8-Oct	20-Jul 18-Oct	30-Jul 28-Oct
	31-Oct	0	0	0	29	61			
	10-Nov	0	0	0	53	96	90		
Beginning date of	20-Nov	0	0	31	92	139	133	119	
land preparation for	30-Nov	0	0	70	129	168	172	152	131
summer paddies	10-Dec		34	112	173	203	203	194	171
	20-Dec			156	203	203	203	203	203
	30-Dec				203	203	203	203	203

[*] Pre-Harvest Drainage Date (PHDD) comes 3 months later.

Table 4.1.2 Estimated water requirement for land preparation (average) for summer paddies by the beginning date of preparation (continued)

(b-1) Average for one month   (mm, 10% probability)

| | | | Beginning date of land preparation for rainy paddies[*] | | | | | | | |
| | | | 21-May | 31-May | 10-Jun | 20-Jun | 30-Jun | 10-Jul | 20-Jul | 30-Jul |
		(PHDD)	19-Aug	29-Aug	8-Sep	18-Sep	28-Sep	8-Oct	18-Oct	28-Oct
	31-Oct		39	77	110	124	115			
	10-Nov		73	99	143	161	154			
Beginning date of	20-Nov		93	140	167	186	190			
land preparation for	30-Nov		115	161	187	195	201			
summer paddies	10-Dec									
	20-Dec									
	30-Dec									

(b-2) Water requirement for the day

| | | | Beginning date of land preparation for rainy paddies[*] | | | | | | | |
| | | | 21-May | 31-May | 10-Jun | 20-Jun | 30-Jun | 10-Jul | 20-Jul | 30-Jul |
		(PHDD)	19-Aug	29-Aug	8-Sep	18-Sep	28-Sep	8-Oct	18-Oct	28-Oct
	31-Oct		0	0	10	60	74			
	10-Nov		0	0	32	77	110	109		
Beginning date of	20-Nov		0	11	77	118	153	146	130	
land preparation for	30-Nov		0	47	113	158	193	189	173	137
summer paddies	10-Dec			91	154	202	203	203	203	177
	20-Dec				198	203	203	203	203	203
	30-Dec					203	203	203	203	203

[*] Pre-Harvest Drainage Date (PHDD) comes 3 months later.

4.2.5 Discussion

According to the results of the water requirement estimations in Table 4.1, if the rainy paddy season is shifted one month earlier, W for the rainy paddies is increased from 0 mm to 10 mm and from 0 mm to 31 mm, while W for the summer paddies is decreased from 197 mm to 120 mm and from 201 mm to 161 mm at probabilities of 25% and 10%, respectively.

Although a small amount of water is needed to prepare the rainy paddies one month earlier, such a shift decreases the total water requirement from 197 mm to 130 mm and from 201 mm to 192 mm, respectively, for the two seasons, both at the probabilities of 25% and 10%. It is seen that with very little supplementary water, the rice season of the rainy paddies can be shifted one month earlier, thereby avoiding inundation-related damage to the transplanted plants and crop yields. If both seasons are simultaneously shifted earlier by one month, W for the rainy paddies increases to 57 mm and 95 mm while W for the summer paddies decreases to 43 mm and 77 mm by decreasing the total water requirement of the land preparation for both seasons from 197 mm to 100 mm and from 201 mm to 172 mm at probabilities of 25% and 10%, respectively.

The reduction of W for summer paddies comes from the effective use of rainfall in the latter period of the rainy season. The reduction in the land preparation water requirement would contribute to an expansion of the summer paddy area or to a reduction in the impact of the domestic water supply for Yangon City. On the other hand, by transplanting one month earlier, the plant will achieve nearly twice the height that it would if planted at the beginning of June, and it will not be subject to inundation of the already-saturated fields during the heavy rains of July (Fig.4.10). Although there is no data available on the area of inundation damage, such inundation damage is widely known to occur in this region. Therefore, shifting of the transplantation season of rainy paddies by one month could substantially benefit this area.

Here it is, however, noted that a potential problem with the shift in the rainy paddy season remains to be discussed—namely, such a shift would move the harvesting into a period of higher rainfall. Figure 4.11 shows the frequency of rainy days above 5 mm by daily and moving 3-day total rainfall during the latter part of rainy season, from September to October.
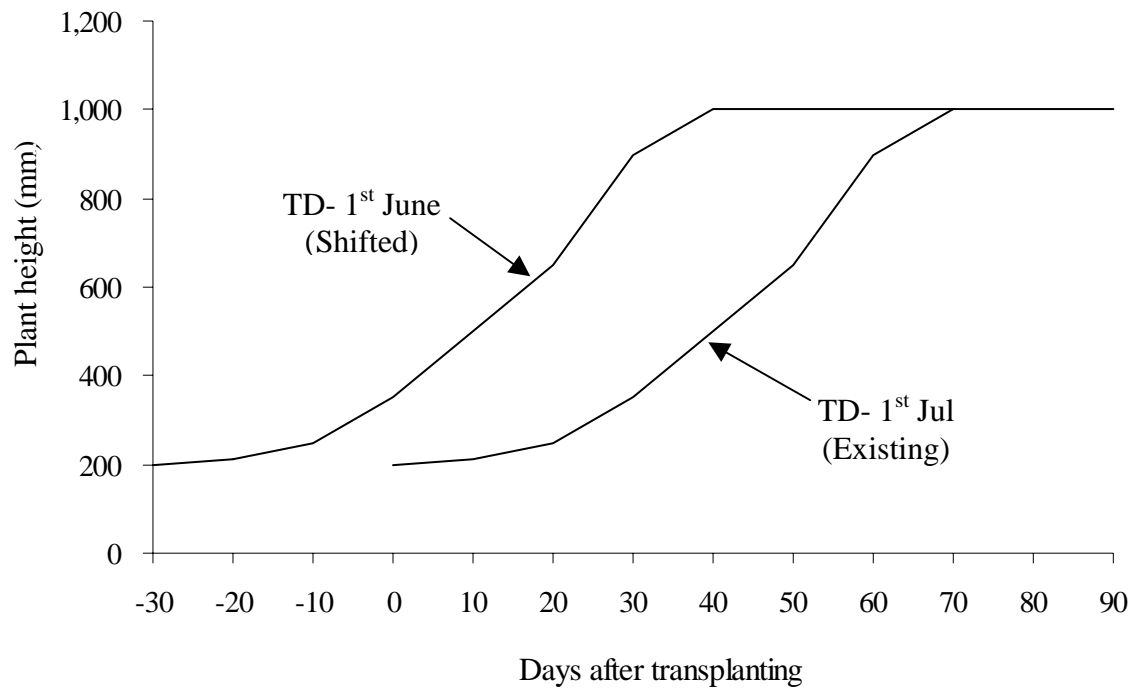
Fig.4.10 Rice plant growth after transplanting

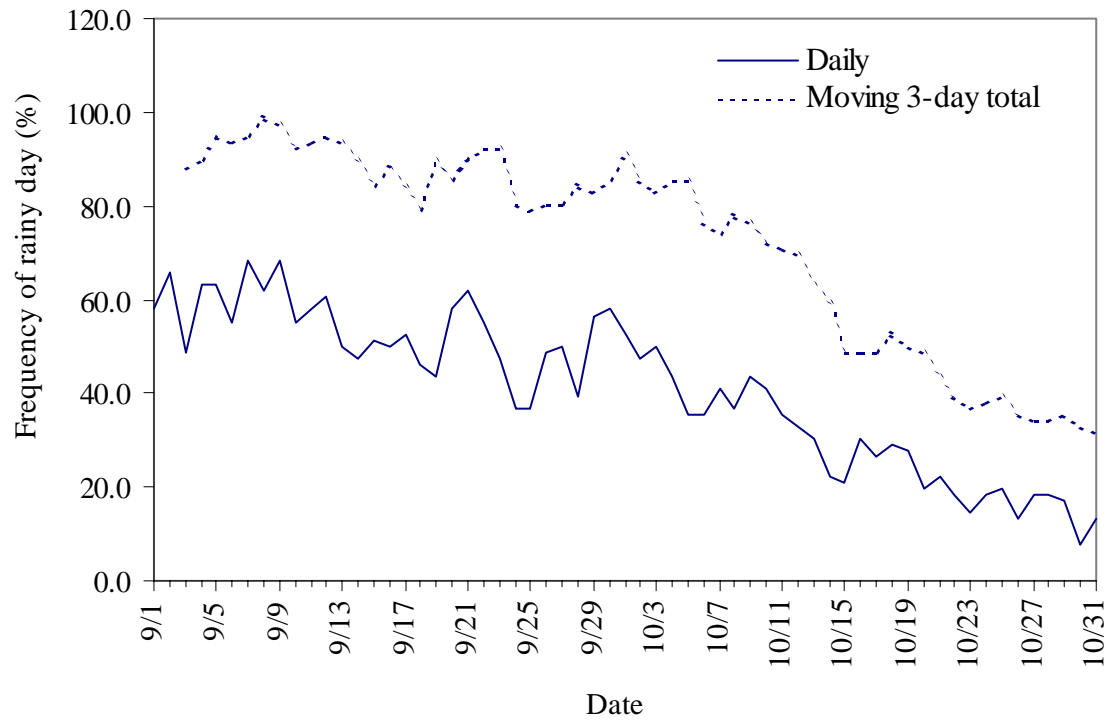**Source**: Takuya Ichihashi (2002)

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Fig.4.11 The frequency of rainy day above 5 mm during the latter part of the rainy
season, from September to October

It shows that the harvesting during September will be stressed by rain, and it can avoid only from the middle of October. This should be discussed from the other viewpoints.

However, based on the above results, the rice season can be shifted one month earlier either for only the rainy paddies or for both the rainy and summer paddies, and such a shift will even allow a decrease in the water-storage requirement for the reservoir.

4.3 Conclusion

(1) Rainy paddies are traditionally cultivated with the goal of securing water for transplanting, which currently starts at the beginning of July. This results in a serious inundation problem during the intense rainfall of the rainy season.

(2) It is possible to avoid the inundation problem and expand the area of the summer paddies by shifting the cropping season one month earlier. This is because earlier transplanting results in increased plant height during the high rainfall period, while the water resources during the latter period of the rainy season can be used for preparing the summer paddies.

(3) The rainy paddy season can be shifted one month earlier without increasing the total water requirement for land preparation of summer and rainy paddies. Such a shift can significantly reduce the risk of rice plant damage due to inundation, since the plant heads will be higher and will be above the surface of the water during heavy rains.

(4) It may also be possible to shift the summer paddy season earlier with less water requirement for land preparation. However, for its realization the farmers are requested to keep water in the paddy fields after harvesting the rainy paddies in preparation for the next land preparation.

4.4 Summary

Even in drought years, the region receives a stable rainfall for rice cultivation, with the annual minimum rainfall being 2,000 mm and the annual average being 2,540 mm. The rainfall approaches its stable stage in the last 10 days of May, and reaches stability in June. The maximum rainfall intensity occurs in the last 10 days of July. The farmers do not start the transplanting until the date of the year; even they get secure water from the rain. The soil is surely saturated at the end of June each year, thus

the farmers start the transplanting from the beginning of July. It causes the young plant to be easily inundated by concentrated heavy rain during July. The rainfall in the region shows its stability and durability during rainy season, from June to September. Therefore, the amount of rainfall between June and July is identical. However, their discharge amounts are substantially different: the runoff ratio is 25% for June and 63% for July. This means that flooding is less possible in June.

The rainfall of 3-day total is below the 100 mm at the several probabilities, thus it cannot inundate the rice. The special characteristics of rainfall in the region are that the 15-day rainfall, which can inundate nurseries, decrease as the time becomes earlier from the beginning of July to the end of May, while the short-term, 3-day rainfall remains constant over the month of June, July, and August. The decreasing ratios of the rainfall for the period are 22%, 31% and 28% at probabilities of 20%, 30% and 50%, respectively. Thus, by shifting the transplanting season of rainy paddies to begin at an earlier date, both flood and inundation damages by heavy rain on the transplanted nurseries can be avoided.

Due to the results of estimated water requirement for land preparation, the amount of water needed for the earlier transplanting of rainy paddies by the rainfall deficit in the beginning rainy season can be supplied by the reservoir storage, without increase in the its total water supply, resulting from the effective use of rainfall. However, the rainfall can stress the shifting harvesting in the latter part of rainy season.

Chapter 5

Evaluation of Water Resources Management in the Reservoir for Paddy Irrigation in Tropical Monsoon Asia

– A Case Study of the Ngamoeyeik Project, Lower Myanmar –

5.1 Introduction

Rice is widely cultivated in monsoon Asia. In this region, the year is divided into two seasons depending on the hydrological conditions, a wet season and a dry one. Rice has been cultivated mostly by monsoon rain during the wet season. However, the season during which rice is cultivated differs from place to place according to the local hydrological conditions. In regions where irrigation projects have been initiated, summer paddies are also cultivated as a second rice crop during the dry season, using reservoirs and irrigation systems. This is a common practice in this region.

A traditional rice cropping season adopted in a region should be regarded as an optimum season for the farmers because of their long experience on the hydrology, or many successes and failures in rice cultivation due to the amount and timing of monsoon rain. However, it often causes such problems of flood and drought damages in rice production. The unstable water supply under rainfed condition is a major problem in traditional rice cultivation, one that has been addressed by the use of reservoirs and irrigation systems. Irrigation projects can also increase second rice cultivation during the dry season. In most irrigation projects, there are still problems with inundation of the rice during the wet season, and water shortages during the dry season.

Reservoirs play a major role in modifying the uneven distribution of water both in space and time, and also make the best use of the available water under the optimal operation (Nandalal et al., 2002). Under proper operating conditions, reservoirs can solve the problem of uneven water supply and increase rice productions.

As an additional function, reservoirs can allow farmers to change the traditional rice cropping season. However, the reasonable and acceptable changes of the cropping season can be affected by, and are related to, the hydrological characteristics that are

present and the water resources facilities that are being used. It is necessary to analyze these interrelationships and influences to foster better rice production. Currently, hydrologists and engineers have an insufficient amount of recorded data upon which to base their analyses. This is also a common problem in monsoon Asia.

In the traditional cropping season in Lower Myanmar, the farmers there do not start transplanting the rainfed paddies until the date of the year when they can get secure water from rain any year, thus young plants often suffer from the inundation damage. After construction of an irrigation project using a reservoir, summer paddies can be irrigated during the dry season. However, there are still water constraints because of the limited water storage in the reservoir. As the reservoir is used only in the irrigated summer paddies, there are still inundation and water shortage problems in both the wet and dry season paddies with the existing cropping season.

As the results and discussion in relation to the rainfall characteristics that described in chapter 4, the traditional paddy cropping season in Lower Myanmar can be shifted one month earlier, and it can significantly reduce the risk of rice plant damages due to inundation (Maung Maung Naing et al., 2003a). To solve these problems, shifting the cropping season has been proposed so that it starts one month earlier in both paddies can solve inundation and water shortage problems. This was discussed only from the viewpoint of water requirement category at the farm plot level. However, an overall evaluation of this proposal, taking into account water resources management and the special characteristics of hydrology in the region, which has a tropical monsoon Asian climate of high temperatures and distinct wet and dry seasons, is needed. The water resources management in the reservoir is affected by the inflow pattern, storage capacity, overflow at the spillway, evaporation, and seepage losses.

The purpose of this research in this chapter is to analyze the influences shifting the cropping season would have on water resource management, and to better understand how to effectively use the reservoir in the Ngamoeyeik Project in Lower Myanmar.

The data recorded before and after construction of the project were used in the analyses. Due to the shortness of inflow data on the reservoir, synthesized flow data were used in the simulation of water storage in the reservoir.

5.2 Materials and Methods

5.2.1 Outline and Characteristics of the Study Area

The detail description of the outline of the Ngamoeyeik Project is presented in the chapter 3. Here, the main features of the reservoir are also presented in Table 5.1. As mentioned in chapter 3, rice is cultivated in the area twice a year after the irrigation project; the rainy paddies from June to November under totally rainfed conditions during the wet season, and the summer paddies from December to May only by irrigation during the dry season. Water from the reservoir is still used only to irrigate summer paddies in the area. During the last 6 years, from 1996-97 to 2001-02, an average area of 14,000 ha was irrigated for summer paddies within the project area. High Yielding Variety (HYV) rice with a life span of 135 days is mostly cultivated in the area.

In the existing cropping season, rainy paddies are transplanted from the beginning of July and summer paddies are broadcasted from the beginning of December. Both paddies are cultivated entirely in the rainy and dry periods, respectively (Fig.4.2). There is often inundation damage to the young plants during the high rainfall period, and water shortage problems in the summer paddies, due to the limited storage in the reservoir in the dry season. In the proposal to shift the rainy paddy season one month earlier, a certain amount of water needs to be stored in the reservoir for the paddies at the beginning of the shifted season. This will require increased storage during the dry season, which may result in an increase in loss by evaporation under high air temperatures (Fig.4.2), as well as decreased availability of water for summer paddy irrigation.

5.2.2 General Methods

To analyze the influence shifting the irrigation seasons would have on the water resources management, the performance of the Ngamoeyeik reservoir under the conditions of the existing and shifted irrigation seasons was simulated, and the results in detail over every factor in relation to the water budget of the reservoir are compared. According to the stochastic feature of hydrology, 100-year synthesized inflow data that maintained the statistical characteristics of hydrological discharge data were used. The simulation results were discussed for two drought years at probabilities of 10% and 20%.

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Table 5.1 The main features of the Ngamoeyeik reservoir

Items	Measure	Unit	Remark
Reservoir type			Within-year reservoir
Catchment area	414.50	km^2	
Capacity	222.00	MCM	
Dead storage	15.00	MCM	
Active storage	207.00	MCM	
Main dam - length	1.86	km	Earthen
- height	22.90	m	
4 saddle dams - length	2.87	km	Earthen
Irrigable area	28,330	ha	
Irrigated area	14,000	ha	Average (1996/97-2001/02)

MCM – million cubic meter

The paddy irrigation requirement was considered separately for the two seasons in terms of requirements for land preparation and growing. The design value of 203 mm was applied for land preparation, and the effective rainfall was also considered when estimating the land preparation water requirement. The irrigation requirement for the growing season cannot be easily determined, because water recycling is widely performed at the on-farm level. Therefore, it was estimated based on the records of water supply from the reservoir during the last 6 years. Estimation of evaporation from the water surface of the reservoir followed the method applied by the Irrigation Department, which designed and manages the project. Seepage was estimated according to a relationship between the water level and loss, which was developed in the study by using the discharge in the creek before the construction, and inflow and evaporation in the reservoir after the construction.

5.3 Irrigation Requirement

An average irrigation requirement for the growing season was calculated based on the amount of water supplied in the irrigated area. It was calculated based on a 10-day average, and given by

$$\overline{IS}_j = \frac{1}{n}\sum_{i=1}^{n} \overline{IS}_{ij} \, , \tag{5.1}$$

where $\overline{IS}_{ij}$ is a 10-day average irrigation (mm/d) for the jth period and ith year, n is the number of years, j is the period of each 10-day group, and $\overline{IS}_j$ is the average irrigation supply (mm/d) at the jth period for the summer paddy growing season. The estimated values are presented in Fig.5.1. It shows that an average daily irrigation of 8 mm is required for the entire growing season if the gradual progress of land preparation is considered. This value was used in the simulation.

5.4 Estimation of Evaporation and Seepage Losses

Major water losses in reservoirs are caused by evaporation and seepage. These amounts are directly related to the reservoir water level; the amount of evaporation is larger on a wider water surface, which generally comes from a higher water level.
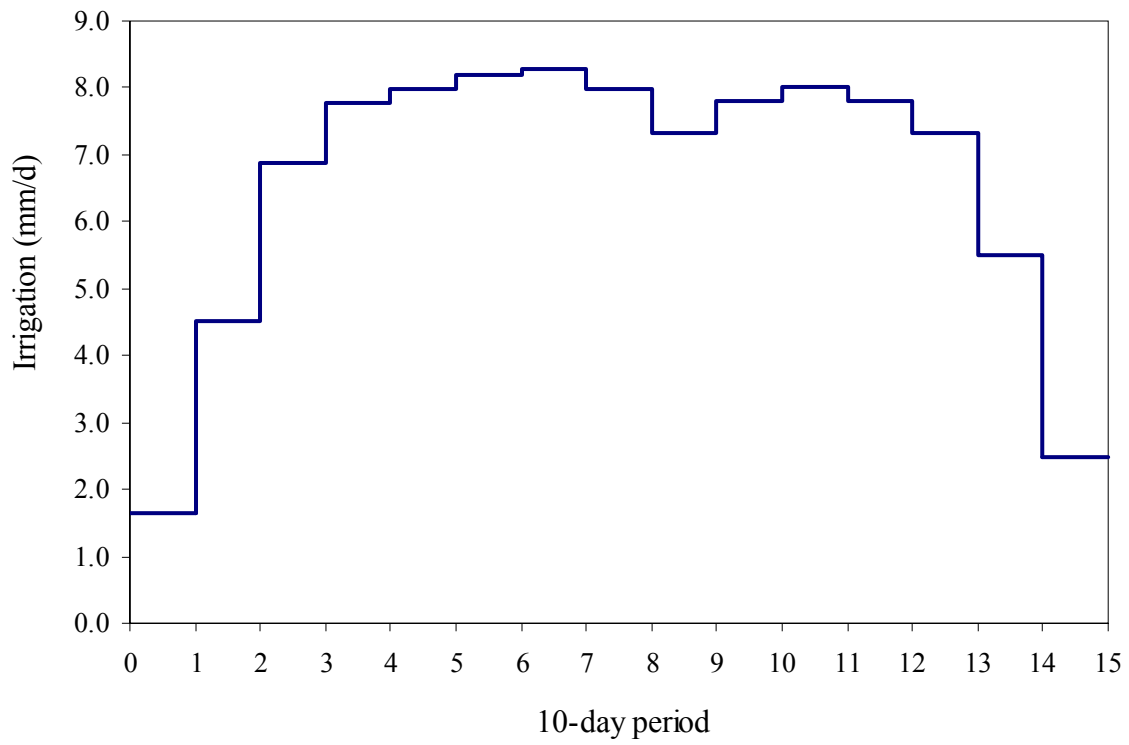
Fig. 5.1 The average irrigation water supply in each 10-day from December to April
during 1996/97 – 2001/02

Seepage is also greater when the water level is higher, because there is more water pressure and a larger wetted zone. These losses must be considered in reservoir operation planning. However, they cannot be easily predicted and known.

It was considered that the evaporation and seepage losses from the reservoir would be greater in the proposed operation than in the existing one, because in the shifted operation, the certain amount of water must remain in the reservoir for the shifted rainy paddies after the summer paddies are harvested. At that time, during March and April, the reservoir evaporation rate is the highest in the project. However, the amount of the additional losses cannot be known in advance, because the water level and water surface are not proportional to the water storage, but dependent on the shape of reservoir. To assess the losses, the general equation of water budget in the reservoir was used. It is expressed as follows.

$$I_i = S_{i+1} - S_i + (E_i + SP_i) + (OF_i + IR_i) , \qquad (5.2)$$

where S_i and S_{i+1} are the storages at the ith and $i+1$th periods, and I_i, E_i, SP_i, OF_i and IR_i are the inflow, evaporation, seepage, overflow at the spillway, and irrigation release during the ith period, respectively. However, I_i cannot be directly known, because evaporation and seepage are not given by direct observation. Therefore, the apparent inflow, I_{ap}, is normally used, which is the real availability of water given as follows,

$$I_{ap} = I_i - (E_i + SP_i) . \qquad (5.3)$$

Figure 5.2 shows the average value of the recorded discharge and the calculated apparent inflow to the reservoir after dam construction. It shows that the losses from evaporation and seepage are very high, and thus the apparent inflow during the dry season becomes negative. This is a typical tendency for reservoirs in the Asian monsoon region, where the water area is large, the temperature in the dry season is extremely high, and dams are long and made with earth, while the actual inflow is extremely limited.
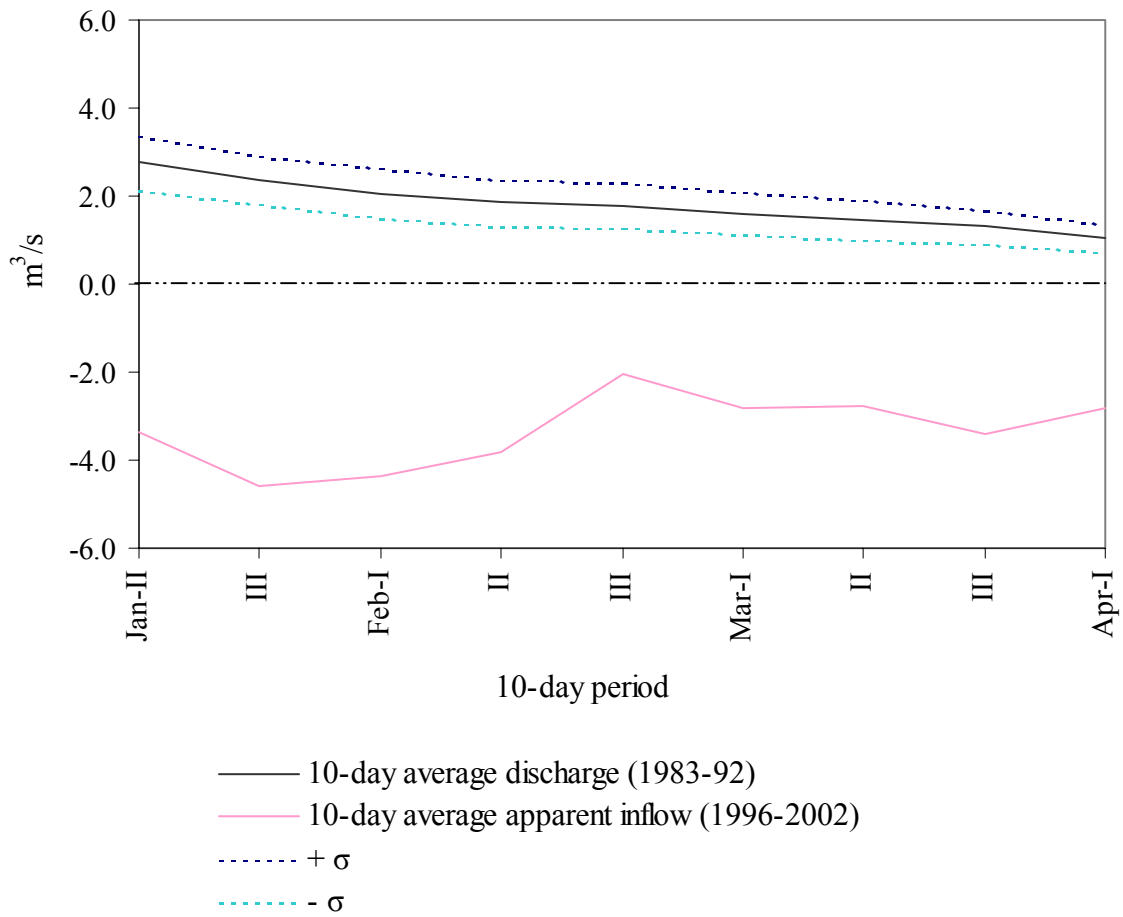
Fig. 5.2 10-day average flow during the dry season
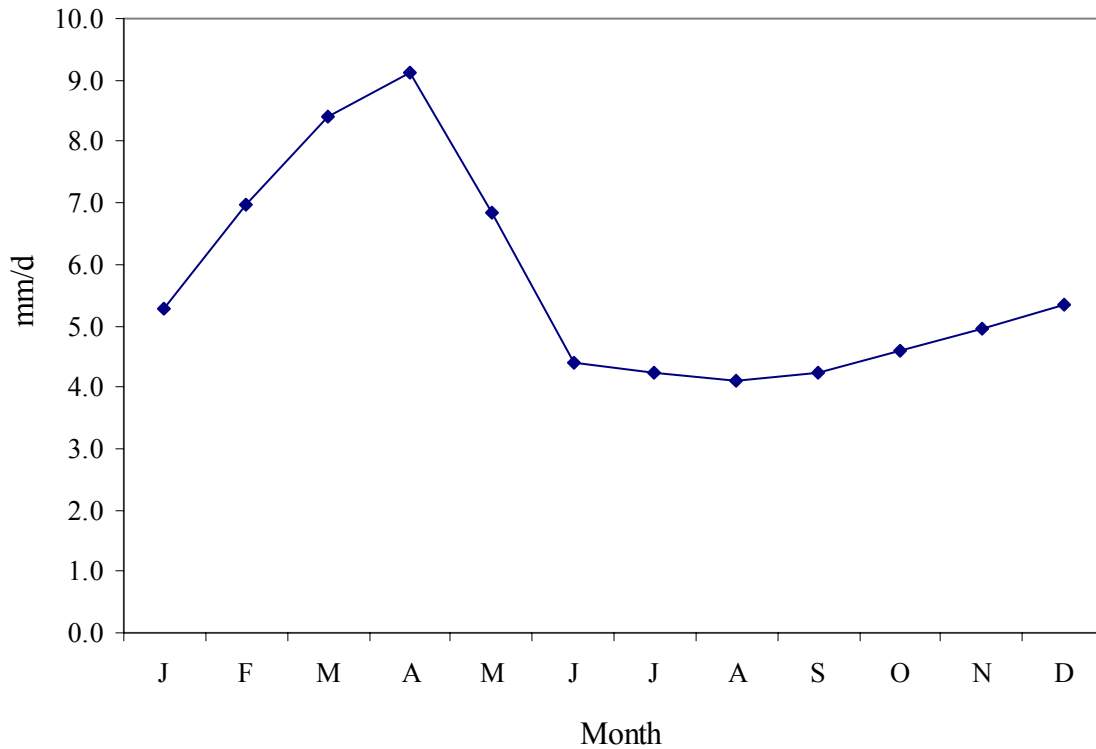
Fig.5.3 Average evaporation in each month

Source: The Irrigation Maintenance Office, Hlegu

In this paper, evaporation from the reservoir, E, was estimated by

$$E = f \times A, \qquad\qquad\qquad (5.4)$$

where f is the daily average evaporation rate for the month (mm/d), which is used in the reservoir water budget calculation by the Irrigation Office, Hlegu (Fig.5.3), and A is the water surface area.

Estimation of the seepage losses was more difficult, because there is no general theory or practical methods to estimate the actual seepage loss for an individual reservoir. The only possible method of estimation could be used, therefore, was the empirical method.

Here, it can be understood that the water level in the reservoir has been decreasing quite steadily every year during the dry season, as shown in Fig. 5.4. The water level showed no significant difference over the years, especially for the period from January to April; the standard deviation of the water level on the same day for the period (10-day interval) ranges from only 0.1 to 0.3m (0.3 to 1% in the coefficient of variance) for the 7-year period. This suggests that the seepage loss during the last 7 years depended on the date.

During the dry season of the past 17 years, especially for the period from Jan. 11th to April 10th, there has been no rainfall. Therefore, the discharge during the season has not been influenced by rainfall, except the rainfall during the preceding rainy season. Thus, if a hypothesis is introduced that the average discharge during the 10 years before and 7 years after the dam construction are the same, the total loss can be estimated as the difference between the lines of the discharge and the apparent inflow in Fig.5.2. Figure 5.4 also includes the estimated standard deviation for the 7-year average, which was calculated from the standard deviation of the discharge recorded before the dam construction. This standard deviation is regarded as small enough to separate the losses. Thus, the seepage loss, SP, was estimated by the equation

$$SP = I_{ac} - (I_{ap} + E), \qquad\qquad\qquad (5.5)$$

where I_{ac} is the actual 10-day average discharge in the creek before the dam construction, which was calculated for the period of 1983-1992, and I_{ap} is the apparent 10-day average inflow into the reservoir during the period of 1996-2002, and E is the 10-day average evaporation during the same period after the dam construction.

Figure 5.5 shows the result of the seepage loss estimation, plotted to the reservoir water level. It can be seen that the seepage reasonably increases as the water level becomes high, despite the fact that there must be various kinds of errors in the hydrological data. For simplicity, two straight lines were developed to estimate the seepage loss from the water level as follows.
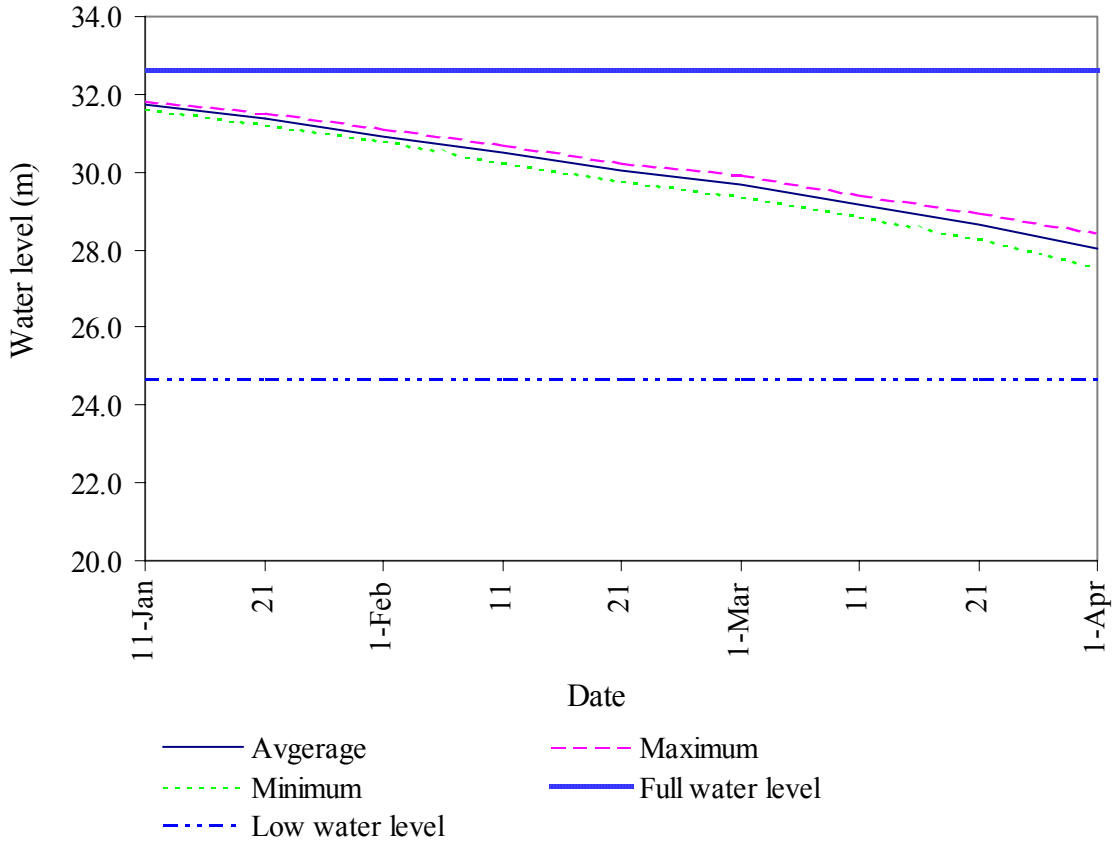
Fig. 5.4 The average water level in the Ngamoeyeik reservoir during the dry season
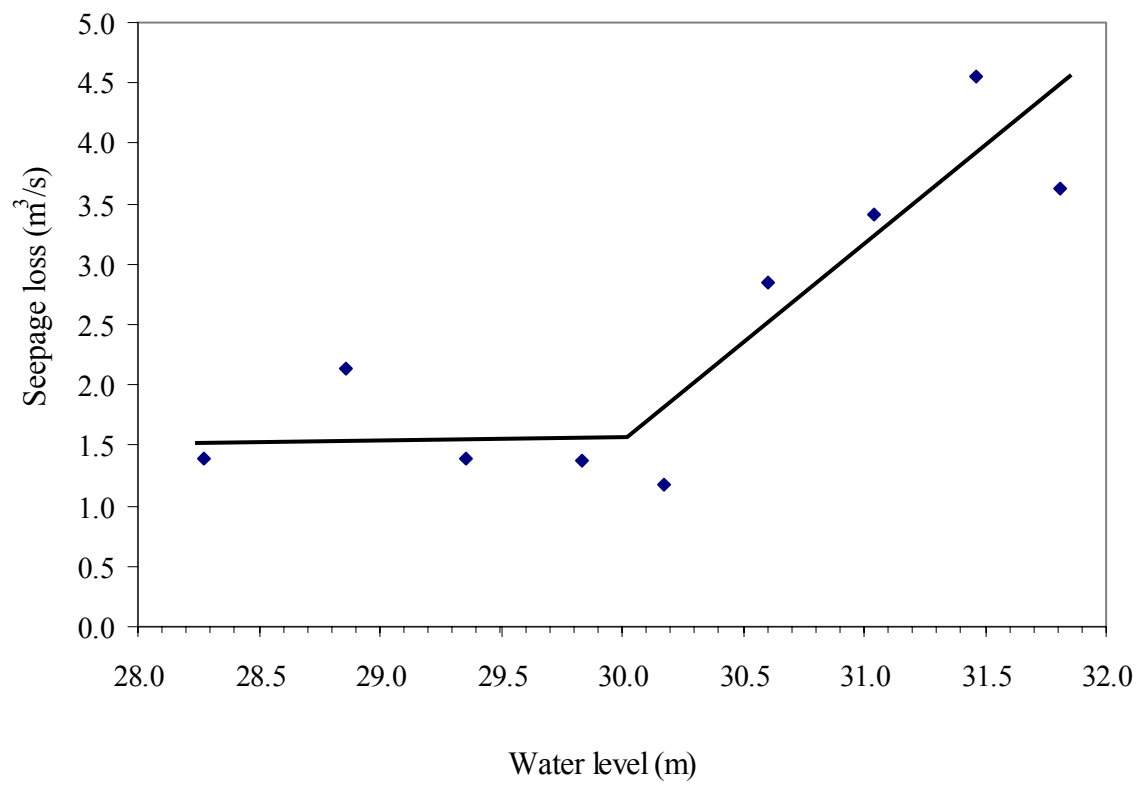from January to April

Fig.5.5 The relationship between water level and seepage loss

If $WL \leq 30.03$ m

$$SP = 0.036WL + 0.62, \qquad\qquad (5.6)$$

and if WL 30.03 m

$$SP = 1.569WL - 45.42. \qquad\qquad (5.7)$$

These estimated values were applied in the simulation.

5.5 Synthesized Streamflow

Synthesized streamflows are a useful tool in water resources planning, design, and operations providing a large number of flows (Fiering, 1967, Fiering et al., 1971, Maass et al., 1962). The fulfilment of this operational hydrology is very applicable, especially where only an insufficient amount of data collected over an insufficient length of time is available. The Thomas-Fiering Method (Thomas et al., 1962) is one of the most useful and widely used synthetic flow models. It has been applied to estimate the reservoir capacity requirement (Raheem et al., 2002). Satoh et al. (1995) studied the applicability of this model in reservoir capacity requirements in Japan, and found a reliable agreement in the capacity requirement and preservation of the statistical parameters of the recorded data.

This model was applied to generate the flow to provide data over a long enough period of time for the simulation of water storage in the reservoir. The flow was synthesized from the 10-year data (1982-1992) recorded before the dam construction. The flow of this model is given by

$$Q_i = \overline{Q}_i + b_i(Q_{i-1} - \overline{Q}_{i-1}) + t\sigma_i\sqrt{1 - r_i^2} , \qquad\qquad (5.8)$$

where Q_i and Q_{i-1} are the discharges in the ith and (i-1)th periods, respectively, reckoned from the start of the synthesized sequence, $\overline{Q}_i$ and $\overline{Q}_{i-1}$ are the observed average 10-day discharge at the respective periods, b_i is the regression coefficient of

Q_i from Q_{i-1}, σ_i is the standard deviation of Q_i, r_i is the correlation coefficient between Q_{i-1} and Q_i, and t is a random normal deviate with zero mean and unit variance. In the generating flow, the values for t were estimated based on the **Box and Muller** Method (Wakimoto, 1970). The choice of t by this method is given as follows.

If $X_1, X_2, X_3, \ldots\ldots\ldots X_n$ is a random data series, the first two data of X_1 and X_2 give;

$$t_1 = (-2 \log_e X_1)^{1/2} \cos 2 \quad X_2, \qquad\qquad (5.9)$$

and

$$t_2 = (-2 \log_e X_1)^{1/2} \sin 2 \quad X_2, \qquad\qquad (5.10)$$

and then the next two data of X_3 and X_4 give;

$$t_3 = (-2 \log_e X_3)^{1/2} \cos 2 \quad X_4, \qquad\qquad (5.11)$$

and

$$t_4 = (-2 \log_e X_3)^{1/2} \sin 2 \quad X_4. \qquad\qquad (5.12)$$

A series of $t_1, t_2, t_3, t_4, \ldots\ldots\ldots t_n$ is used as the values for t in the generating flow by the Thomas-Fiering model, when it has a random normal deviate with zero mean and unit variance as $N(0,1)$ (Fig.5.6). It can be estimated by trial test. The statistical parameters in the observed flow data (Table 5.2) were used in generating flow.

The flow was generated by the 10-day discharge from October to June every year. A lag-one model was mostly applied to generate the flow. In the Thomas-Fiering model, a normal or lognormal flow is usually applied, due to the observed flow distribution. In the preliminary study, it has been understood that the characteristics of the flow are a normal distribution in the dry season and a lognormal distribution in the wet season (Maung Maung Naing et al., 2003b). A normal distribution was applied in the model. It can avoid an extremely large value of the flow discharge in the dry season.

Table 5.2 Statistical parameters of the 10-day observed and synthesized flows

Period	Observed				Synthesized	
	m		*r*	*b*	*m*	
Oct I	226.32	107.43	-	-	220.94	99.46
II	239.06	213.07	-0.05	-0.10	249.42	188.08
III	136.40	74.43	0.50	0.17	132.96	68.68
Nov I	75.33	43.36	0.43	0.25	78.08	37.68
II	114.09	102.55	0.06	0.14	127.74	83.54
III	47.36	27.32	0.31	0.08	47.46	23.67
Dec I	39.94	29.47	0.94	1.02	39.80	25.21
II	37.05	31.17	0.99	1.05	37.48	26.52
III	37.28	26.60	0.91	0.77	38.64	21.72
Jan I	29.13	17.88	0.76	0.52	30.40	14.88
II	27.54	15.87	0.94	0.83	29.03	13.66
III	23.52	14.43	0.97	0.88	25.11	12.67
Feb I	20.60	14.88	0.96	0.99	22.55	12.92
II	18.60	13.91	0.99	0.93	20.76	11.98
III	17.94	13.87	0.99	0.99	20.06	11.86
Mar I	15.96	12.66	0.97	0.89	18.22	10.71
II	14.52	12.01	0.96	0.91	16.68	10.16
III	12.96	10.66	0.97	0.86	14.79	9.10
Apr I	10.37	8.21	0.90	0.69	11.41	6.88
II	11.09	9.38	0.98	1.12	12.30	7.95
III	9.58	7.98	0.89	0.76	10.00	6.29
May I	8.21	7.63	0.83	0.79	8.43	5.49
II	13.86	9.76	0.48	0.62	14.79	8.73
III	58.46	115.93	0.66	7.78	82.76	83.74
Jun I	109.30	103.56	0.05	0.05	114.09	90.22
II	246.81	310.46	0.21	0.62	271.21	241.01
III	277.19	212.15	0.80	0.54	308.28	165.33

m = average flow, m^3/s,   *r* = correlation coefficient

   = standard deviation, m^3/s,   *b* = regression coefficient
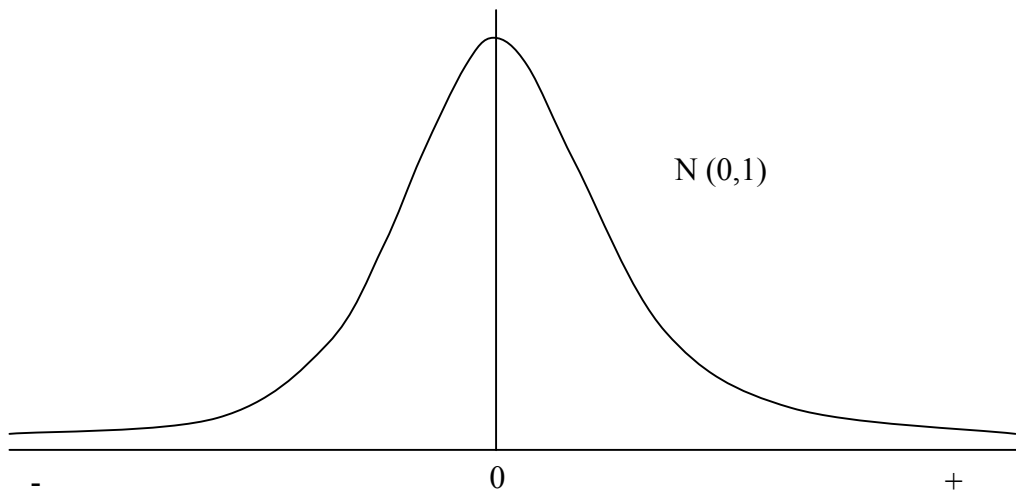
N (0,1)

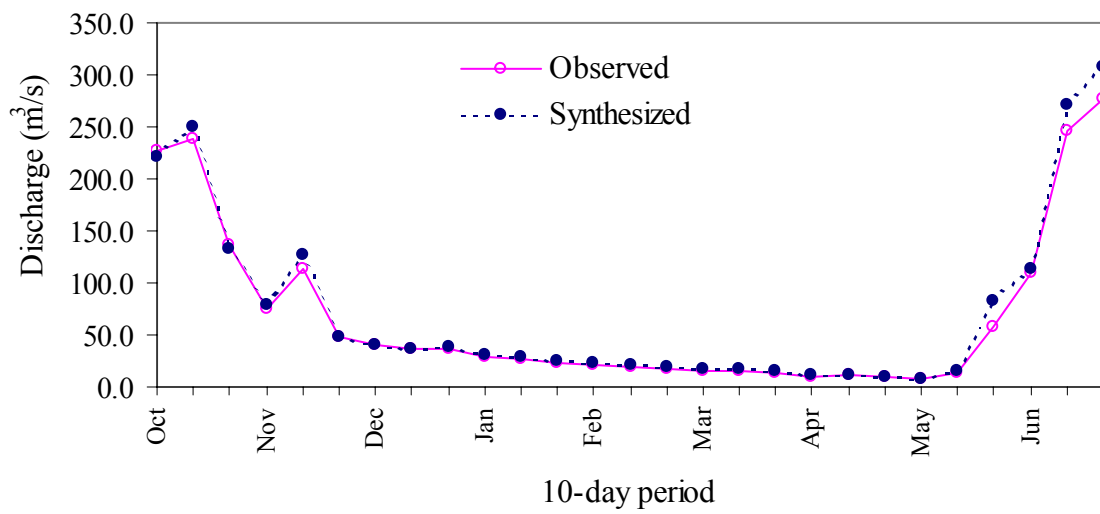Fig.5.6 A normal distribution of *t* with N (0,1)

Fig. 5.7 Average 10-day discharge of the observed and synthesized flows in the
Ngamoeyeik creek

The initial flow discharge for the first 10-day in October for each year was estimated by

$$Q_i = \overline{Q} + t_i \sigma \,,$$
(5.13)

where Q_i is an initial flow at the ith year, and $\overline{Q}_i$ and σ are a mean and standard deviation in the observed flow of the first 10-day in October, and t_i is a random normal deviate with zero mean and unit variance.

In order to discuss the distribution of the reservoir storage, the flow was synthesized for 100 years. The result gave a good fit in average flow and standard deviation (Table 5.2, Fig.5.7). The flows were used in the simulation of water storage in the reservoir.

5.6 Method for the Reservoir Storage Simulation

The reservoir capacity required to supply a certain yield for a given sequence of inflows can be determined by successive application of the water balance equation, and then the probability distribution function of the capacity can be known by using synthetic flow sequences generated by an appropriate streamflow model (Bayazit et al., 1991). Generally, reservoir systems exist as two classes: over-year (year-to-year) and within-year (non-year-to-year) systems. The Ngamoeyeik reservoir is a within-year system. It spills every year. The storage is at full stage at the beginning of the summer paddy season, is then gradually drawn down by irrigation, and reaches the empty stage in active storage at the beginning of the rainy season. A behavior (or simulation) analysis (McMahon, 1993) was performed to learn the distribution of the storage at the beginning of the rainy paddy season under a given condition of water use. This simulation makes it possible to compare the security of water availability for rainy paddy irrigation between the shifted and existing cropping seasons.

The basic equation for the simulation is

$$S_{i+1} = S_i + I_i - IR_i - (\overline{OF_i} + \overline{E_i} + \overline{SP_i}) \,,$$
(5.14)
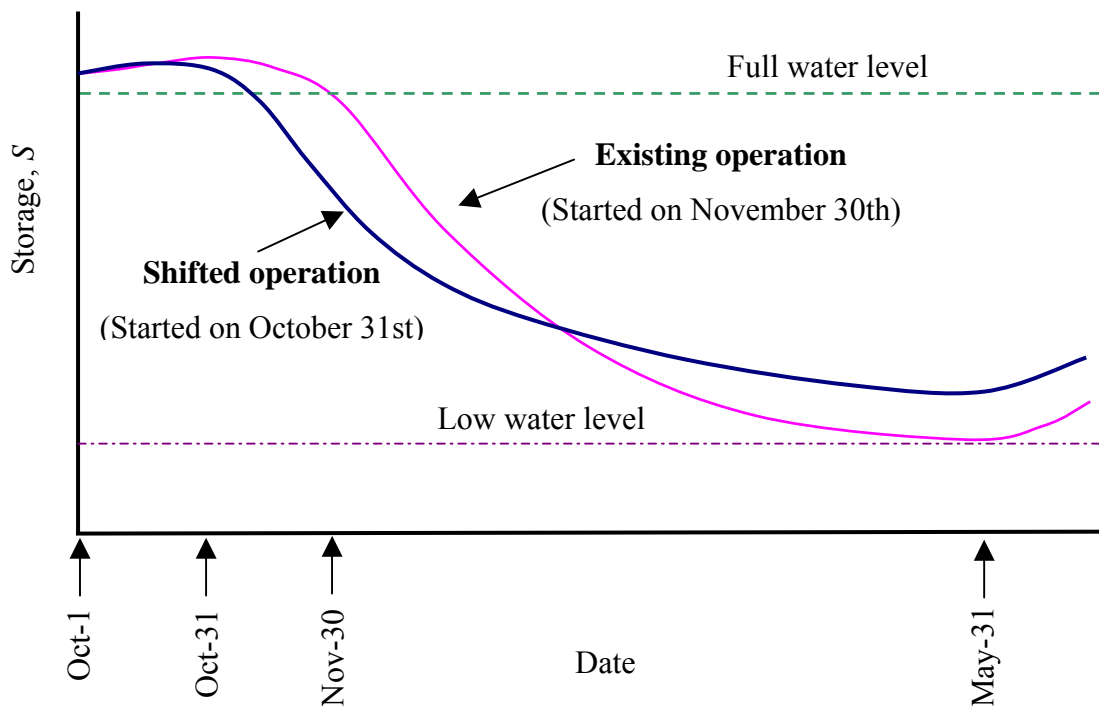
Fig.5.8 The typical diagram of the simulation of water storage in the reservoir for the shifted and existing operations

where

S_i, S_{i+1} = storage at ith and $i+1$th period, respectively,

I_i = inflow during the ith period,

IR_i = irrigation supply during the ith period,

$\overline{OF_i}$ = average overflow during the period from ith to $i+1$th

$\overline{E_i}$ = average evaporation during the period from ith to $i+1$th

$\overline{SP_i}$ = average seepage during the period from ith to $i+1$th.

In order to decide S_{i+1} for this implicit equation avoiding accumulated errors, a successive approximation method was applied as follows.

Let the first approximation for S'_{i+1} by given as

$$S'_{i+1}(1) = S_i + I_i - IR_i \, , \tag{5.15}$$

and the next approximation by

$$S'_{i+1}(j) = S_i + I_i - IR_i - (\overline{OF'_{i,j-1}} + \overline{E'_{i,j-1}} + \overline{SP'_{i,j-1}}) \, , \tag{5.16}$$

where

$S'_{i+1}(j)$ = jth approximation for S_{i+1}

$\overline{OF'_{i,j-1}}$ = the average of overflows at water storages of S_i and $S'_{i+1}(j-1)$

$\overline{E'_{i,j-1}}$ = the average of evaporations at water storages of S_i and $S'_{i+1}(j-1)$

$\overline{SP'_{i,j-1}}$ = the average of seepages at water storages of S_i and $S'_{i+1}(j-1)$.

This loop was continued until

$$S'_{i+1}(j+1) = S'_{i+1}(j) \, , \tag{5.17}$$

and then

$$S_{i+1} = S'_{i+1}(j+1) \, . \tag{5.18}$$

The simulation was performed on a daily basis from the beginning of October to the end of June (Fig.5.8). The initial storage of 247 MCM was fixed on October 1, which is the average value on that date during the last 8 years. This initial day for the simulation is well in advance of the day when the summer paddy irrigation is started, so that the influence of the initial condition is negligible. The designed values of relationships in water level (*WL*)-capacity, *WL*-water surface area, and *WL*-spilling discharge were used in the simulation to calculate the overflows, evaporation, and seepage. Equation (5.4) and equations (5.6-5.7) were applied in the simulation to calculate evaporation and seepage.

The period for land preparation was considered to be one month for the whole area, and it was divided into 3 groups of 10 days. The beginning days of irrigation and the water requirement for land preparation are given in Table 5.3.

Table 5.3 Estimated water requirement for land preparation

(mm, 10% probability)

Season	Group	Beginning date		Water requirement	
		Rainy paddy	Summer paddy	Rainy paddy	Summer paddy
Shifted	1	May-31	Oct-31	95	77
	2	Jun-10	Nov-10	31	143
	3	Jun-20	Nov-20	0	186
Existing	1	Jun-30	Nov-30	0	201
	2	Jul-10	Dec-10	0	203
	3	Jul-20	Dec-20	0	203

Source: Maung Maung Naing et al., (2003a)

The values in Table 5.3, which are the estimated values shown in Table 4.1 (b) in chapter 4, are the water requirement at the exceedance probability of 10%. These values were used in the simulation. It is a safer value in estimation of the remaining water storage at the end of the irrigation season. For the growing season, 8 mm/d was adopted based on Fig.5.1.

The rice-growing season for each group was 135 days, and irrigation was needed for only 120 days, because the surface water was drained 15 days before harvesting after the rice matured. Irrigation started on October 31st and on November 30th for the shifted and existing seasons, respectively. The simulation was applied to a 10,000 ha to 20,000 ha irrigated area of summer paddies in intervals of 2,000 ha. The simulation was performed for 100 years. The synthesized 10-day average flow was evenly distributed for the period as the daily inflow. The probability distribution was calculated by Weibull's formula as the plotting position.

5.7 Results and Discussion

In the shifted season the reservoir has to retain an active storage of 8.97 MCM on May 31st to meet the target water requirements for the rainy paddies of the shifted season. This target storage was calculated for one-third of the project service area (28,330 ha) with a water requirement of 95 mm (Table 5.3). However, there is no need for the reservoir to retain storage for the remaining two-thirds of the area, because the irrigation requirement is covered by inflows obtained during the earlier days.

Figure 5.9 presents the results of the simulation showing the relationship between irrigated areas for summer paddies and remaining active water storage in the reservoir on May 31st at the yearly non-exceedance probabilities of 10% and 20%. It clarifies that more water can be retained in the shifted cropping season than in the existing one for the same irrigated area of summer paddies. With regards to amount of summer paddy areas that can be irrigated under the target remaining storage, the shifted operation allows areas of 15,200 ha and 16,650 ha to be irrigated, while the existing operation allows areas of 14,200 ha and 15,200 ha at the probabilities of 10% and 20%, respectively. This simulation result of 14,200 ha for the existing summer paddy area at the probability of 10% coincides well with the actual present summer paddies of 14,000 ha.
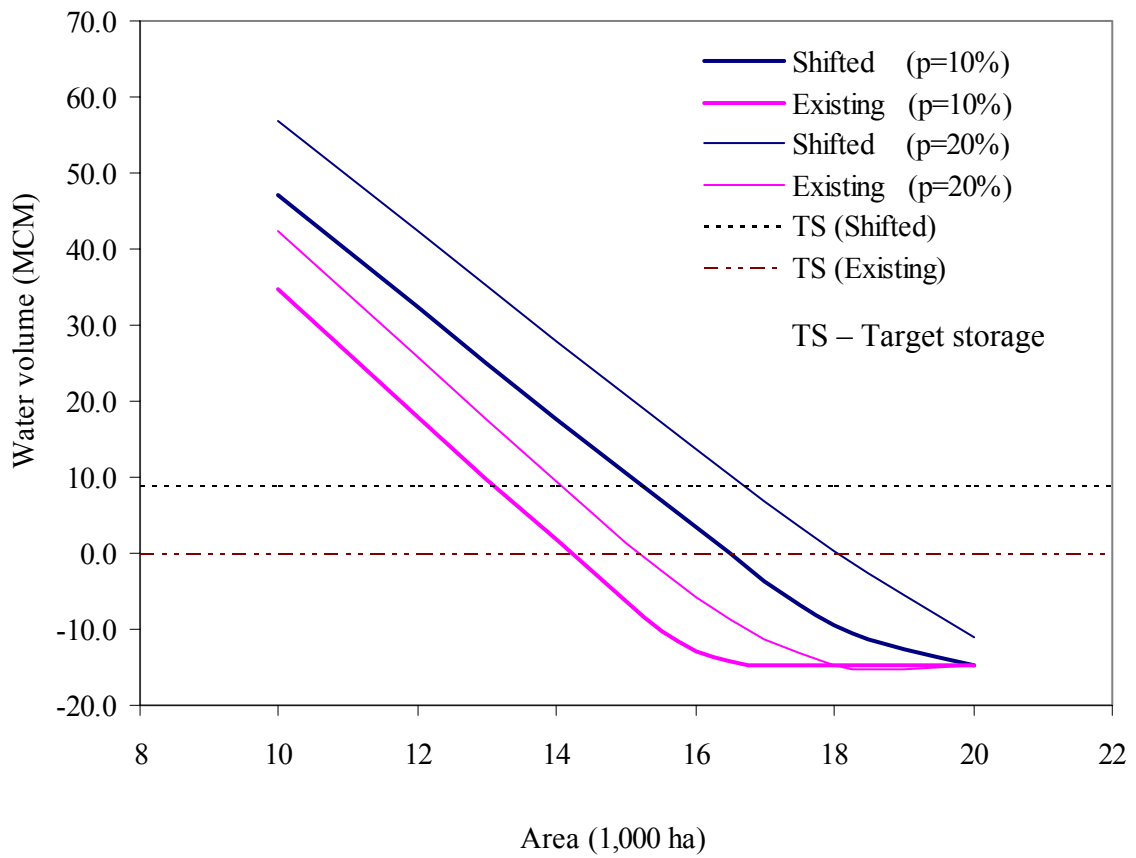
Fig. 5.9 The remaining active storage on May 31 under the existing and shifted
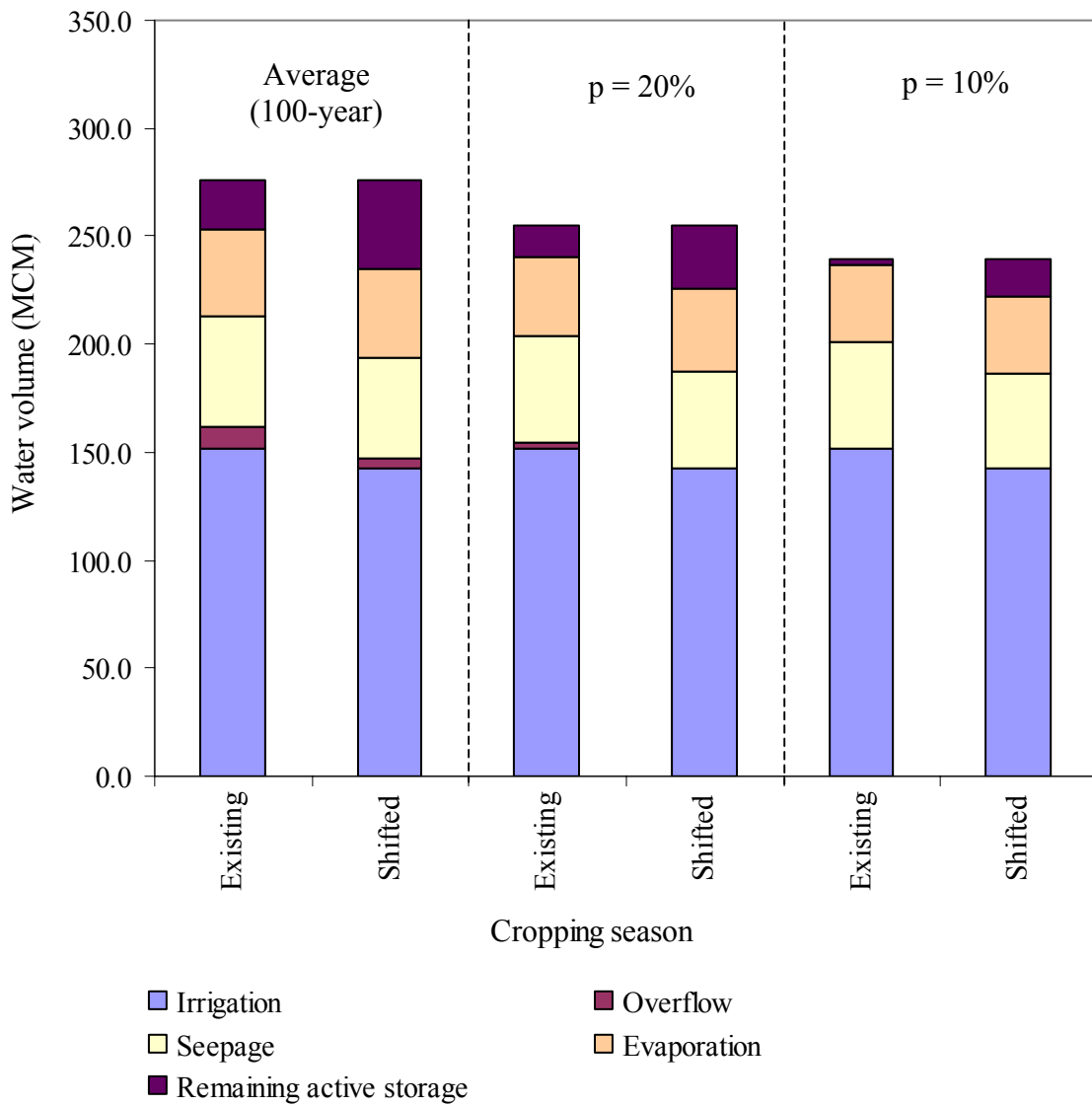conditions of summer paddy

Fig.5.10 Water budget in the Ngamoeyeik reservoir during the dry season under the existing and shifted cropping seasons for summer paddy

The breakdown of the water budget for the period of October 31st to May 30th under the irrigated area of 14,000 ha is shown in Fig.5.10. In this figure, it can be seen that a high ratio of outflow is occupied by the losses of evaporation and seepage: the efficiency of water use in the reservoir is 64% in the existing cropping season, and also 64% in the shifted cropping season for the case of the 10% probability. This high ratio of losses can be regarded as a special characteristic of reservoirs in monsoon Asia, where paddy fields are irrigated using reservoirs under the hydrological conditions of distinct wet and dry seasons with high air temperatures.

A larger amount of remaining active storage in the shifted cropping season means more efficient water use. This advantage comes from fewer overflows at the spillway, and less irrigation requirements and less seepage loss, while evaporation loss increases.

The seepage losses decreased by 10.4% from 48.94 MCM to 43.87 MCM, and 9.8% from 49.81 MCM to 44.94 MCM in the shifted cropping season compared to the existing one at the probabilities of 10% and 20%, respectively. This decrease in the seepage loss resulted from the earlier lowering of the water level in the reservoir.

The evaporation loss increased to 1.4% and 4.7% at the probabilities of 10% and 20%, respectively. It takes place because more water has to be stored in the reservoir for the latter half of the season, when the evaporation rate is high due to extremely high air temperatures.

The advantages and disadvantages of the existing and shifted cropping seasons by item (Table 5.4) were evaluated. Table 5.4 shows general precedence of the shifted cropping season while the harvesting of rainy paddies tends to be hard because of being shifted into the latter part of rainy season (Fig.4.11, section 4.2.5). However, the harvesting of summer paddies is better in the shifted cropping season, because the existing season is sometimes adversely affected by the earlier arrival of the rainy season. This advantage is a product of the special characteristics of the hydrological conditions in Lower Myanmar.

Table 5.4 Evaluation of the existing and shifted cropping seasons by items

Season	Items		Shifted season		Existing season
Rainy paddy	Transplanting		Supplementary irrigation		Rainfed only
	Inundation damage		Avoidable	×	Unavoidable
	Harvesting	×	Hard		Easy
	Rice production		Stable high yield	×	Stable low yield
Summer paddy	Water requirement		Less	×	More
	Water losses		Less	×	More
		Seepage	Less	×	More
		Evaporation ×	More		Less
	Irrigated area		Expandable	×	Limited
	Harvesting		Easy	×	Hard
	Rice production		Stable high yield	×	Unstable high yield
Both paddies	Overflow		Less	×	More
	Rice production		More	×	Limited
	Reservoir		More beneficial	×	Beneficial
	Water resources use		More effective	×	Effective

Preferable   × Undesirable

5.8 Conclusions

The introduction of an irrigation system using reservoirs has the technical possibility of shifting the traditional cropping season, which in Lower Myanmar leads to inundation problems for young rice plants.

A certain amount of water storage is required for the earlier rainy paddies, which would cause an increase in evaporation loss from the reservoir. However, the simulation of water storage in the reservoir has shown that other factors related to the water budget, such as seepage and overflow, could compensate for this, and even increase the availability of water. It has also shown that the evaporation loss in the water budget during the dry season is as high as 16%.

In the shifted cropping season, the irrigated summer paddy area can be expanded by 7% and 9.5% at the non-exceedance probabilities of 10% and 20% for the water resources failures, respectively.

Overall evaluation by item shows the advantages of the shifted cropping season. This result is highly influenced by the special characteristics of the hydrological conditions found in tropical monsoon Asia.

The process and methodology used in this research can be adoptively developed for new conditions of increased water demand and additional water resources development in the project, and elsewhere in Lower Myanmar.

5.9 Summary

The reservoir water availability for the shifted and existing cropping seasons is discussed through the simulation of water storage in the reservoir using the synthetic streamflow discharge data that generated by the Thomas-Fiering streamflow model. The water resources management of the reservoir is affected mainly by the evaporation and seepage losses. The seepage loss can be estimated using the apparent inflow into the reservoir after dam construction and the actual flow discharge before dam construction, and it reasonably increases as the water level becomes high.

The more water in the reservoir at the end of the summer paddy irrigation season can be retained in the shifted season. This is resulted from the earlier lowering of the water level in the reservoir drawn down by the earlier irrigation of summer paddies. It increases the reservoir water availability and water use efficiency.

The efficiency of water use in the reservoir for the summer paddies is 64% in both operations. A high ratio of the reservoir outflow is occupied by the evaporation and seepage losses. The evaporation loss in the water budget during the dry season is as high as 16%. This high ratio and losses can be regarded as a special characteristic of reservoirs in monsoon Asia, where paddy fields are irrigated using reservoirs under the hydrological conditions of distinct wet and dry seasons with high air temperatures.

The reservoir water availability increases in the shifted operation that can avoid inundation damage of the rice in rainy season and water constraint in the dry season. On the other hand, it shows the general precedence of the shifted cropping season while the harvesting of rainy paddies tends to be hard because of being shifted into the latter part of rainy season. However, the harvesting of summer paddies is better in the shifted cropping season, because the existing season is sometimes adversely affected by the earlier arrival of the rainy season. This advantage is a product of the special characteristics of the hydrological conditions in Lower Myanmar.

This evaluation of water resources management in the reservoir shows the much advantages of the shifted cropping season. This result is highly influenced by the special characteristics of the hydrological conditions found in tropical monsoon Asia. The process and methodology used in this research can be adoptively developed for new conditions of increased water demand and additional water resources development in the project, and elsewhere in Lower Myanmar.

Chapter 6

Conclusions and Recommendations

The following points are summarized and recommended for a paddy cropping season development in Lower Myanmar to avoid inundation damages of the rainy paddies, and to foster better rice production through the analysis of rainfall characteristics. The advantages in water resources system of the shifted cropping season are also confirmed based on the simulation analysis for the water resources management in the reservoir.

(1) Rainy paddies are traditionally cultivated with the goal of securing water for transplanting, which currently starts at the beginning of July. This results in a serious inundation problem during the intense rainfall of the rainy season.

(2) It is possible to avoid the inundation problem and expand the area of the summer paddies by shifting the cropping season one month earlier. This is because earlier transplanting results in increased plant height during the high rainfall period, while the water resources during the latter period of the rainy season can be used for preparing the summer paddies.

(3) The rainy paddy season can be shifted one month earlier without increasing the total water requirement for land preparation of summer and rainy paddies. Such a shift can significantly reduce the risk of rice plant damage due to inundation, since the plant heads will be higher and will be above the surface of the water during heavy rains.

(4) It may also be possible to shift the summer paddy season earlier with less water requirement for land preparation. However, for its realization the farmers are requested to keep water in the paddy fields after harvesting the rainy paddies in preparation for the next land preparation.

(5) The introduction of an irrigation system using reservoirs has the technical possibility of shifting the traditional cropping season, which in Lower Myanmar leads to inundation problems for young rice plants.

(6) A certain amount of water storage is required for the earlier rainy paddies, which would cause an increase in evaporation loss from the reservoir. However, the simulation of water storage in the reservoir has shown that the other factors related to the water budget, such as seepage and overflow, could compensate for this, and even increase the availability of water. It has also shown that the evaporation loss in the water budget during the dry season is as high as some 16%.

(7) In the shifted cropping season, the irrigated area for summer paddies can be expanded by 7% and 9.5% at the non-exceedance probabilities of 10% and 20% for the water resources failures, respectively.

(8) Overall evaluation by item shows the advantages of the shifted cropping season. This result is highly influenced by the special characteristics of the hydrological conditions found in tropical monsoon Asia.

(9) The process and methodology used in this research can be adoptively developed for new conditions of increased water demand and additional water resources development in the project, and elsewhere in Lower Myanmar.

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