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Towards Modernization of Water Management System in Upper East Bank of Chao Phraya Delta

-Follow-up Activities of the Modernization of the Water Management System Project in Thailand-

TAKAKI Kyoji*, SHIODA Katsuro**, ARULVIJITSKUL Pongsak***,
KOONTANAKULVONG Sucharit****, HORIKAWA Naoki*****,
PUNYACHOM Athaporn*** and BUDDHAPALIT Atthaporn***

Contents

I　Introduction

Agriculture in the Kingdom of Thailand (Thailand) relies heavily upon the water resources in the Chao Phraya River basin (Fig.1). The basin has an area of 162,000 km^2 and occupies about one-third of the entire area of Thailand. The lower basin is called the Chao Phraya Delta (CPD), which is one of the greatest rice granaries in the Asian monsoon area. The CPD has an area of 13,400 km^2, of which 10,800 km^2 (80.6%) is irrigable. The land elevation of the irrigable area ranges from 0 to 19 m above mean sea level. The annual rainfall in the area fluctuates from 1,000 mm to 1,600 mm. A year is divided into the dry season and the rainy season; the rainy season begins in mid-April and ends in late October. In general, at the beginning of the rainy season, it rains locally and within a short period. Rain is extremely rare in the dry season, and days with no rains occasionally continue for a significantly long period even in the rainy season (Yuyama et al., 2004).

The main water resources in the CPD are the Bhumibol reservoir dam with a storage capacity of 13,500 million cubic meters (MCM) and the Sirikit reservoir dam with a storage capacity of 9,500 MCM. Despite the existence of these

*Laboratory of Water Environment Conservation, Department of Hydraulic Engineering
**The Japanese Institute of Irrigation and Drainage
***Royal Irrigation Department, Ministry of Agriculture and Cooperatives, Thailand
****Department of Water Resources Engineering, Chulalongkorn University, Thailand
*****Laboratory of Agricultural Water Management, Department of Agricultural Environment Engineering
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huge dams, the water shortage of the CPD is chronic because the recent growth of the Thai economy has facilitated the development of an industrial zone, a housing land, and a resort area; this has led to a significant increase in the water demand in the CPD. Moreover, the construction of irrigation facilities has enabled water supply to regions where it had previously been difficult to cultivate rice or field crops in dry seasons, thereby increasing the water demand.

In order to cope with the increased water demand, the Thai government aimed at using the existing water resources more effectively by improving the water management system through improved irrigation facilities and water management technology. Because the agricultural sector accounts for a large part of the water demand, it faces problems such as shortage of irrigation water during dry seasons and the inefficient use of irrigation water at the on-farm level.

Therefore, the Royal Irrigation Department (RID) emphasized on the secure preservation of water resources in the dry seasons by increasing irrigation efficiency so that crop diversification is achieved and the cultivation rate is improved. Because Thailand is the largest rice exporting country in the world, the Thai government intends to stop a further decrease in the price of rice due to the surplus condition in the international market. At the same time, the government aims to secure farmers' income and promote crop diversification instead of rice monoculture during the water shortage period in the dry seasons. Incidentally, the RID defines that the dry season begins in January and ends in June.

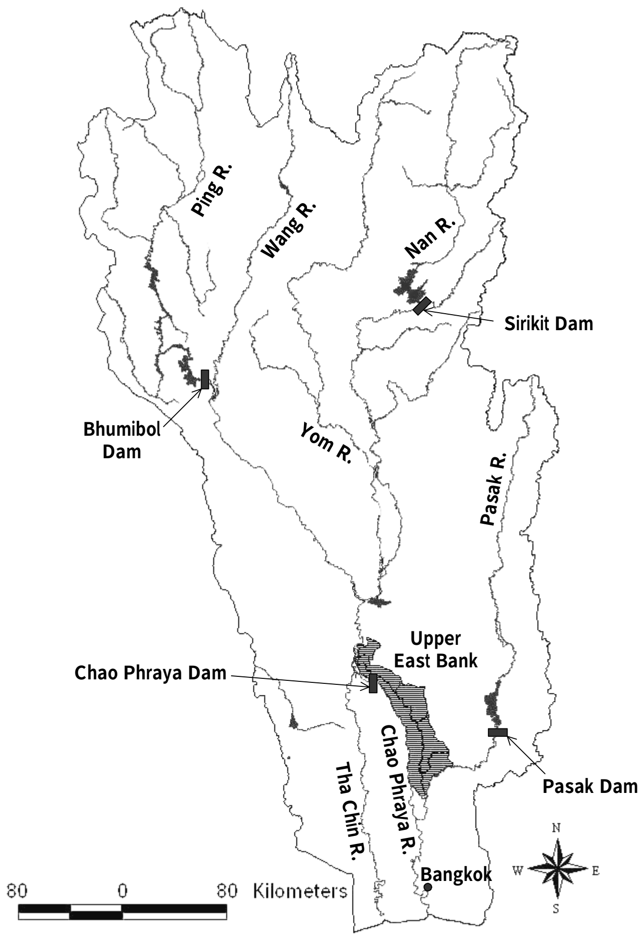


Fig. 1 Outline of the Chao Phraya river basin (Ueda et al., 2005c)

To solve this problem, the Japan International Cooperation Agency (JICA) provided technical cooperation to the government of Thailand, and the Irrigation Engineering Center (IEC) Project (1985-1990) and the IEC Project Phase II (1990-1997) were implemented to develop an appropriate technology with regard to the planning, design, and construction of water-use facilities and establish water management skills. However, the technical maturity for efficient water use was still insufficient and there was scope for further improvement.

In response to this, the Modernization of Water Management System (MWMS) Project had been implemented by the RID and the Department of Agricultural Extension (DOAE) under the technical cooperation of the JICA since April 1999. The target area of the MWMS Project was set at the Upper East Bank (UEB) of the CPD (Fig.2), and the development of on-farm level water management and farming methods, the improvement of basin and delta level water management technology, and the training for government staff and farmers group leaders were carried out.

The UEB is administrated by the Regional Irrigation Office 10 (RIO 10) of the RID. With regard to water management, the target area mainly consisted of four operation and maintenance irrigation offices (O&M offices): Manorom, Chong Khae, Khok Kathiam, and Roeng Rang along the Chainat-Pasak main canal, as shown in Fig.2. Each O&M office operates one main regulator in the main canal and intake gates or pumps at the mouths of several lateral canals. At the same time, the water users' organizations on the 18R lateral canal, which is 9,972 m long with a total area of 16,000 rai (1 rai = 0.16 ha), in the Khok Kathiam O&M office were strengthened. The 18R area is also known as the model area, and the development of the on-farm facilities and the dry-season field cropping were performed in this area.

The MWMS Project was scheduled to conclude at the end of March 2004. However, it was extended by one and a half years due to the failure of dry-season field cropping and unfair water distribution along the Chainat-Pasak main canal, although the achievements of this project were considerable.

This paper presents the results of the follow-up activities in the basin and the delta-level water management of the MWMS Project. In chapter II, the activities of water management before the follow-up program are briefly reviewed. An outline of the activities in the follow-up program is provided in chapter III, and significant results are reported in chapter IV. In chapter V, the recommendations are presented for the further sophistication of water management, and chapter VI concludes.

The authors would like to express special thanks to the members of the basin and delta level working group of the MWMS Project. Our thanks are also due to the staff of the RID, DOAE, and JICA who worked together with us. Dr. Tatsuki Ueda and Dr. Yoshito Yuyama, the former JICA experts on water management, provided us with guidelines for our activities and valuable advice. Ms. Warunee Sodprasert, the secretary of Dr. Kyoji Takaki who is the JICA expert on water management in the follow-up program and one of the authors of this paper, helped us with interpretation and coordination between the Japanese and Thai staff.

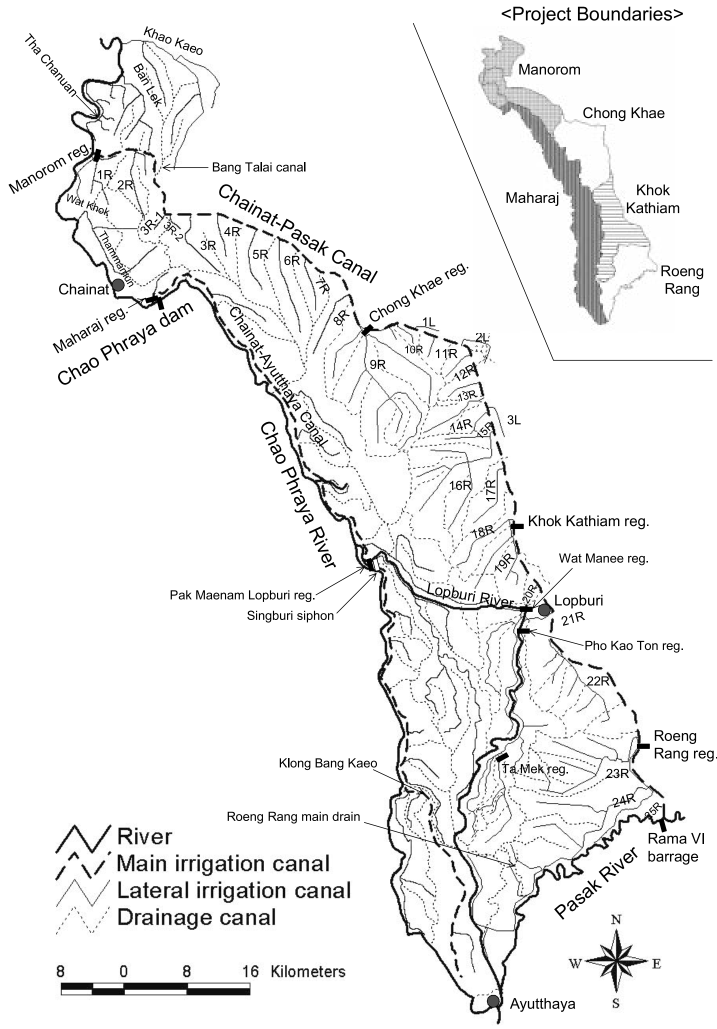


Fig. 2 Outline of the UEB of the Chao Phraya delta (Ueda et al., 2005c)

II Review of the Modernization of Water Management System Project

Since the former JICA experts have previously reported the outcomes of the MWMS Project with regard to water management (Yuyama et al., 2002, 2003a, 2003b; Ueda et al., 2005a, 2005b, 2005c), we introduce the results that are particularly related to the activities in the follow-up program. During the first five years of the project, the following goals were achieved with regard to water management. These outputs were compiled as guidelines (MWMS project, 2003) and reproduced in textbooks for training and seminars with regard to this project.

1) Development of the decision support system (DSS)

The decision support system (DSS), which has a man-machine interface, is expected to contribute to more efficient water allocation planning and practical water management. The DSS that we are developing consists of four subsystems, namely, monitoring, database, analysis, and reference. In order to accurately monitor existing water conditions and share this information, summarized information is essential. The DSS will also be useful to explain the reasonableness of water management for solid engineering grounds. Moreover, the development process of the DSS is very important because RID officials can share the information and discuss the method of water allocation with each other. In this sense, we believe that the sustainable development of the DSS will contribute to the construction of a modernized water management system in Thailand.

(i) Pilot project of the telemetry system

The pilot project of the telemetry system was executed in the lower part of the Chao Phraya River. After its completion, the operation of the system was started in September 2003. There are eight remote stations along the river that transmit data on water level, rainfall, and water quality to the main station at the RID headquarters. The hydrology data are sent from the remote stations of the telemetry system to the computers of the master station at the RID headquarters in Bangkok every 15 min and analyzed by several programs such as the flood-forecasting program. These data are also sent to the Bangkok Metropolitan Authority, the Public Works Department, and the King's Project Office as well.

(ii) Data collection with e-mail reports

Previously, the local staff of the RID reported water management data to the O&M offices by phone, radio transceivers, and so on. The O&M offices then transmitted the data to the RIO and the RID headquarters by fax. In general, the data was not recorded in a digital format, and the RID headquarters could not analyze the data quickly. The e-mail report system was then introduced in order to aid data collection and the quick analysis of the water management data for the RID headquarters. The O&M office inputs the data on a prescribed form and sends them as an e-mail attachment file. After receiving the e-mail, the RID headquarters can export the data to the database with a single click.

(iii) Water management database and geographical information system (GIS) layers

After the dry season, we can utilize the "Database Menu" application that we developed by using Microsoft Access to simplify and improve the summary study of the dry season irrigation. We also uploaded our database system onto the Internet to provide easy access for the local offices to the latest water management data. The database and geographical information system (GIS) layers can be accessed from the website of the RID. Therefore, this data can be utilized to compare the plan with the actual amount of allocated water.

2) Understanding the target area further

In order to formulate a more practical water allocation plan, the following activities were carried out with the cooperation of specialists such as system engineers, researchers on runoff or water balance.

(i) Remote sensing analysis

A remote sensing analysis of the land-use conditions was conducted in the UEB. As a result, a land-use map, which would be useful for water management, was created. In addition, a remote sensing analysis of the inundation conditions of the Chao Phraya River basin during the rainy season in 2002 was conducted.

(ii) Runoff analysis

A lateral inflow runs from the left bank of the Chainat-Pasak main canal to the target area in the rainy season. This inflow could be used as irrigation water in the UEB. In order to determine the amount of lateral inflow, we collected the additional data ourselves because the left bank area is located outside the target area. We began data collection for the area in August 2003, and runoff analysis was attempted. However, we could not obtain sufficient data due to the drought. Consequently, this activity was carried out in the follow-up program of the MWMS Project.

(iii) Water balance analysis

To understand the water flow in the UEB, discharge measurements and water balance analysis were conducted simultaneously. We could estimate the sources of irrigation water for each hydrological block; however, we could not obtain sufficient results for the actual water distribution due to the lack of hydrological and water management data. This analysis is further examined in the follow-up program by using additional data.

3) Understanding the actual situation and identification of problems

Various activities were conducted in order to understand the actual situation of water management, and several problems were identified with regard to the modernization of water management (Ueda et al., 2005a, 2005b, 2005c). Although Ueda offered some beneficial and helpful proposals to the RID before the follow-up program, the following serious problem persisted:

(i) Unfair water distribution along the Chainat-Pasak main canal in the dry season

The most important problem of the water management was the unfair water distribution between the four O&M offices along the Chainat-Pasak main canal. The two upstream offices used excessive irrigation water compared with the two lower offices. In addition, the actual intake volume of irrigation water was far greater than the target value. As a practical countermeasure, we launched a monthly "Water Allocation Regulating Committee" (WARC) meeting in the dry season in 2004.

III Outline of the outputs and the activities in the follow-up program

The follow-up program of the MWMS Project is described by the Project Design Matrix (PDM) Version 4, which was designed in March 2004. PDM is a table in which the outline of the project is compactly arranged in a particular form. The activities, outputs, and the purpose of a project and the overall and highest goal are described in the leftmost row. Important assumptions to achieve them are written as an external risk to the rightmost row. Further, the objectively verifiable indicators and the means of verification to measure the degree of achievement of the outputs and the purpose are listed in the two rows at the center. Table 1 shows the project purpose, outputs, and objectively verifiable indicators excerpted from the PDM Version 4. Each output (1-5) corresponds to the activity in the field with regard to on-farm facilities, water management, water users' organization, farming, and training, and the objectively verifiable indicators are determined for each field.

Regarding water management, a weekly water allocation plan at the lateral canal level must have been formulated and implemented in the target area along the Chainat-Pasak main canal according to the objectively verifiable indicator for the project purpose. Before the follow-up program, the weekly water allocation plan had been formulated every year; however, irrigation water was distributed in a haphazard manner because the farmers strongly requested water to the O&M office according to their convenience of cultivation and the RID staff accepted these requests (Ueda et al., 2005a, 2005b, 2005c). Furthermore, by the end of June 2005, the ratio of the actual value to the planned value with regard to the total amount of water distribution in the dry season must have been regulated within a range of 100% ± 30% in all the four O&M offices along the Chainat-Pasak main canal. In fact, the ratio for Manorom, Chong Khae, Khok Kathiam, and Roeng Rang district was 206%, 168%, 112%, and 128% in the 2002 dry season and 182%, 153%, 170%, and 152% in the 2003 dry season. Thus, the excessive water intake in the upper districts and the large gap between the planned and actual water distribution reflected the unfair water allocation, which was a serious problem.

The above objectively verifiable indicators have been successfully achieved through the untiring efforts of the project participants. The achievements are as follows:

1) The water allocation plan in the dry season was formulated and implemented on the basis of the consensus of the RID headquarters and the RIOs in the CPD, RIO 10 and the relevant O&M offices in the UEB, the Khok Kathiam O&M office, and the integrated water users' group (IWUG) in the 18R model area.

2) The WARC was newly organized by the staff of the RID headquarters, the RIO 10, and relevant O&M offices after the terminal evaluation of the MWMS Project in 2003.

3) The actual water allocation and the planned value were discussed at the monthly WARC meeting, and the results were used for water allocation thereafter.

4) The indicator was achieved. The ratios of the actual value to the planned value against the total amount of water distribution in the 2005 dry season from upstream to downstream were 72%, 107%, 121%, and 109%. As a result, fair water distribution was achieved along the Chainat-Pasak main canal.

In order to realize the purpose of the above project and its outputs, the plan of operation (PO) was determined for each working field. The PO for water management is described in Table 2. Several activities had already been completed by the end of March 2004, and the following steps were executed in the follow-up program:

1) 2-1-2-C. Development of a decision support system for practical water operations

(i) An integrated system comprising the water management database and the GIS was developed and launched in May 2004. The developed system is utilized as a part of the DSS on water management.

2) 2-1-2-D. Application of the proposed water management method in the UEB of the CPD

(i) A training course on the usage of the integrated system comprising lectures and activities for prospective members was held in May 2004.

(ii) The actual situation and problems of the water management along the Chainat-Pasak main canal were discussed at the monthly WARC meetings. The results of the discussion were applied to actual water management.

(iii) The technique of runoff analysis and water balance analysis was taught to the members through on-the-job training and working group meetings.

3) 2-1-2-E. Improvement in dry-season irrigation planning and operation

(i) The WARC meetings were held four times in the 2004 dry season (from April to June) and eight times in the 2005 dry season (from December to July).

Table 1 Project Design Matrix (PDM) Version 4 (excerpted table)

Project Purpose	Objectively Verifiable Indicators
In the irrigation period of the dry season, through effective irrigation water utilization, the planted acreage of the field crops in this season in the model area (18R canal area) is increased and crop diversification is promoted.	Non-paddy field crops are successfully harvested by more than 50% of the farmers who attempted field cropping in the dry season in the model area; a weekly water allocation plan at the lateral irrigation canal level is formulated and implemented in the Chainat-Pasak canal command area.

Outputs	Objectively Verifiable Indicators
1 In the model area, on-farm level irrigation and drainage facilities that are necessary for cultivating both rice in the rainy season and field crops in the dry season and their lateral level irrigation facilities are rehabilitated to serve as a model, and related guidelines are expanded.	1 The guideline for on-farm facilities development for the field crops of the dry season is suitably expanded. By the end of September 2004, the irrigation facilities of the 18R canal within the management section Km.6 are rehabilitated.
2 The water allocation plan for the dry season is formulated on the basis of the consensus of the RID headquarters, Regional Irrigation Office 10, O&M Project Offices, and the integrated water users' group. The water allocation is practiced according to the plan of the CPD for the UEB.	2 By the end of June 2005, the ratio of the actual value to the planned one against the total amount of water allocation in the dry season is regulated within a range of 100% ± 30% in all the four projects along the Chainat-Pasak main canal.
3 Water users' groups that are in charge of the operation and maintenance of the on-farm level irrigation and drainage facilities are established, trained, and strengthened; furthermore, these groups cooperate in order to operate and maintain the irrigation and drainage facilities of the lateral canal level.	3 By the end of September 2003, farmers establish more than 14 water users' groups (WUGs) and 1 integrated water users' group (IWUG) in the model area. RID and IWUG will cooperatively decide the schedule of irrigation water distribution in the 18R area, and based on this decision, RID will operate gates in the 18R canal. More than 80% of WUGs operate and maintain on-farm level irrigation and drainage facilities.
4 Field crops and their cultivation methods that should be promoted to extend cultivation in the dry season are selected; furthermore, farming activities are accelerated by establishing and strengthening the farmers' groups for farming and their support system.	4 Guideline for the cultivation technology for the field crops in the dry season is suitably established in the model area; some examples of crop diversification in the paddy fields during the dry season in the UEB of the CPD are prepared as a reference book.
5 RID, DOAE and farmers' group leaders that are selected to disseminate the project activities are trained through scheduled training courses and seminars by the more experienced members.	5 By the end of September 2005, the experienced members lecture more than 150 staff of the RID and DOAE, and more than 100 farmers were found to comply with the dissemination plan, and more than 2/3 of the trainees understand each lecture.

Table 2 Plan of operation (PO) for water management

Activities
2. Improvement in basin and delta level water management
2-1. Improvement in irrigation and drainage planning and operation of facilities
2-1-1. Analysis and examination of the current situation for efficient water management
2-1-1-A. Clarification of existing problems
2-1-1-B. Preliminary proposal of the new water management system
2-1-2. Examination of efficient water resources utilization
2-1-2-A. Review and analysis of related planning
2-1-2-B. Learning from practical experience
2-1-2-C. Development of a decision support system for practical water operations
2-1-2-D. Application of the proposed water management method in the UEB of the Chao Phraya Delta
2-1-2-E. Improvement in dry-season irrigation planning and operation
2-2. Improvement in the data communication system
2-2-1. Basic design of the data communication system for the Chao Phraya river basin
2-2-1-A. Data collection by the telemetry system
2-2-1-B. Data processing system
2-2-1-C. Display system
2-2-1-D. Data transmission system
2-2-2. Installation of the telemetry system
2-2-2-A. Estimation of the installation cost
2-2-2-B. Preparation of the procurement document
2-2-2-C. Installation at the pilot sites
2-2-2-D. Operation and maintenance of the installed system
2-2-3. Application of remote sensing and GIS technology
2-2-3-A. Estimation of the planted area by R/S (remote sensing)
2-2-3-B. Estimation of the inundated area by R/S
2-2-3-C. Summary of above information by GIS

Note: Prefix number “ 2 ” indicates that the activity belongs to the field of water management.

(ii) The results of water allocation were monitored continuously and the plan was adjusted according to the actual water and cultivation condition.
(iii) The farmers did not comply with the cropping regulation proposed by the RID. This implied that they attempted to continue cultivation throughout the entire dry season. As the result, it became difficult to stop water supply at the end of the dry season.
(iv) The gap between the planned and actual cultivation area still persisted because the farmers cultivated paddies outside the target area.
(v) The cultivation area was categorized into three types according to the types of water resources, and the characteristics of water use with regard to all the four O&M offices were clarified. It was revealed that the farmers used other water resources such as drainage water or shallow well water for their cultivation outside the target area with their own efforts.
(vi) The existent calibration curves of the intake gates at the 23R and 24R lateral canals were modified because it appeared that the estimated discharge significantly differed from the actual discharge due to the rehabilitation of the canals.
(vii) Collection of hydrological data was carried out on the left bank of the Chainat-Pasak main canal, and the volume of water inflow to the canal during the rainy season was analyzed. The average runoff ratio was approximately in the range of 0.03 to 0.13; however, this value was considered to be too low due to inaccuracy and insufficient amount of data. In order to obtain more accurate results, further data collection and analysis should be continued by the members

who have already learned the techniques of runoff analysis.
(viii) As a reference for the above analysis, the tendencies of rainfall and runoff in the catchment area of the Pasak-Jolasid dam were analyzed.
(iv) Simultaneous discharge measurement was carried out eight times, and the water balance was analyzed in the UEB. According to the analysis, if the water supply in the rainy season is reduced by 10%, half of it can be stored in the reservoirs, and the irrigation area in the dry season can be increased by 10%. The constructed water balance model will be used for the estimation of water inflow and outflow in the target area hereafter.
4) 2-2-2-D. Operation and maintenance of the installed system
(i) Operation and maintenance of the pilot telemetry system was monitored.
(ii) Follow-up survey on the pilot telemetry system was carried out. Most of the problems experienced immediately after the system had been installed still remained; however, a working team for the maintenance of the telemetry system was introduced in March 2005.

IV Significant results of the activities for water management

1 Fair water distribution along the Chainat-Pasak main canal

As described in chapter II, the resolution of unfair water distribution along the Chainat-Pasak main canal was the most important problem with regard to water management. In this section, we describe in detail the condition of the water resources, the water allocation plan, and the results of the 2005 dry season obtained by the follow-up program. This is because the water level of the main canal decreased due to the water shortage, and the quantity of water intake to the lateral canals was not measured accurately in the 2004 dry season.

a General condition of the water resources

The water resources that can be used in the dry season depend on the precipitation in the rainy season of the previous year; however, the rainfall in Thailand varies greatly from 1,000 to 1,600 mm, depending on the year as described in chapter I. In reality, the rainfall in the rainy season was sufficient in 2000-2002, and farmers could enjoy abundant irrigation water in corresponding the dry seasons. However, immediately before launch of the follow-up program, the rainfall in the 2003 rainy season was insufficient; it was insufficient in 2004 as well. For instance, in 2005, the combined rate of effective storage capacity at the Bhumibol and Sirikit dam decreased from 58% to 20% during the six months of the dry season. The seriousness can be understood from the fact that the average rate of effective storage capacity was about 50% at the end of the dry season from 2000 to 2003. Therefore, water management in the dry seasons in the follow-up program was severely affected by this drought condition.

b Water allocation plan

The Chainat-Pasak main canal is targeted for water management in the dry season. There are four O&M offices, in Manorom, Chong Khae, Khok Kathiam, and Roeng Rang along the canal. The water allocation plan of the CPD for the dry season is formulated based on the basis of the consensus of the RID headquarters and the RIOs that always exchange information on water requirements with the O&M offices. Fig.3 shows the plan for the east bank of the CPD in the 2005 dry season. The total amount of allocated water for the east bank was 1,810 MCM. 1,310 MCM of water is supplied by both the Bhumibol and Sirikit dam, and 500 MCM of water is supplied by the Pasak dam, which is one of the reservoirs in the lower Chao Phraya River basin. 615 MCM of water is supplied to the Chainat-Pasak main canal as irrigation water from both the Bhumibol and Sirikit dams. The amount of water allocation is determined based on the estimation of the unit water requirement for each crop and its planned cultivation area.

c Practical water management in the UEB

After the total amount of water for allocation in the dry season is determined, RIO 10 begins preparing the weekly water allocation plan for each lateral canal. This target water allocation plan is made for the RID on the basis of the ideal cropping pattern. Therefore, the significant difference between the target and the actual water allocation increased every year due to unplanned cultivation by the farmers. In particular, in each of the four districts along the Chainat-Pasak main canal, the lateral canals are connected to the main canal and are well constructed. Further, the farmers can obtain water from the main canal by using their own pumps even if the RID staff intends to keep the intake gate of the lateral canal closed. Moreover, the farmers have continued to makes demands to the O&M offices for water, thus disregarding the water allocation plan. Due to this, the operation of water allocation by disregarding the plan became the usual state of affairs even in the O&M office. As a result, the excessive water intake in the upper districts reduced the water intake in the lower districts, thereby leading to unfair water distribution in the four districts.

In order to solve the above problem, the WARC was introduced in the 2004 dry season. At their monthly meeting, the committee members confirm the water resources situation, report their cultivation condition and requests from the farmers, and discuss the following course of action for water allocation. Consequently, they were able to understand each other's situation and resolve the problem of unfair water distribution to some extent.

d Water distribution results in the 2005 dry season

The RIO 10 was supposed to receive 1,210 MCM of water in the 2005 dry season; however, the actual amount of water distribution was 1,851 MCM despite the water shortage situation. Meanwhile, the actual amount of water distribution to the four districts along the Chainat-Pasak main canal was 614 MCM, which was close to the planned value. This figure shows that irrigation water was used efficiently in the areas of these four districts. This implies that the difference in the actual amount of water distribution and the planned value for RIO 10 was supplied to the lower CPD.

Fig.4 indicates the results of the target and actual water distribution in the 2005 dry season. It can be observed that the farmers require irrigation water throughout the dry season, although the target water allocation is only for single paddy cropping during the dry season. This implies that the farmers will always cultivate rice plants in the paddy fields where water can be obtained throughout the year. However, due to the water shortage of this year, the total amount of water intake is suppressed to a low value as compared with that of the wet year. In Fig.4, the accumulated A/T ratio that is the ratio of the amount of actual water distribution to that of the target is indicated. When evaluated in terms of the accumulated A/T ratio, the ratio does not fluctuate significantly, excluding January when irrigation started, and it settles down in the neighborhood of 100% at the end of June when irrigation ends. Fig.4 (a) shows that the A/T ratio in the Manorom district is relatively lower than that of the other districts throughout the dry season. This is because the WARC decided to leave the gates of the Chong Khae regulator open during the dry season; this suppresses the water level of the main canal, thus avoiding excess water intake in the Manorom district. The ratios of the actual value to the planned value with regard to the total amount of water distribution from upstream to downstream

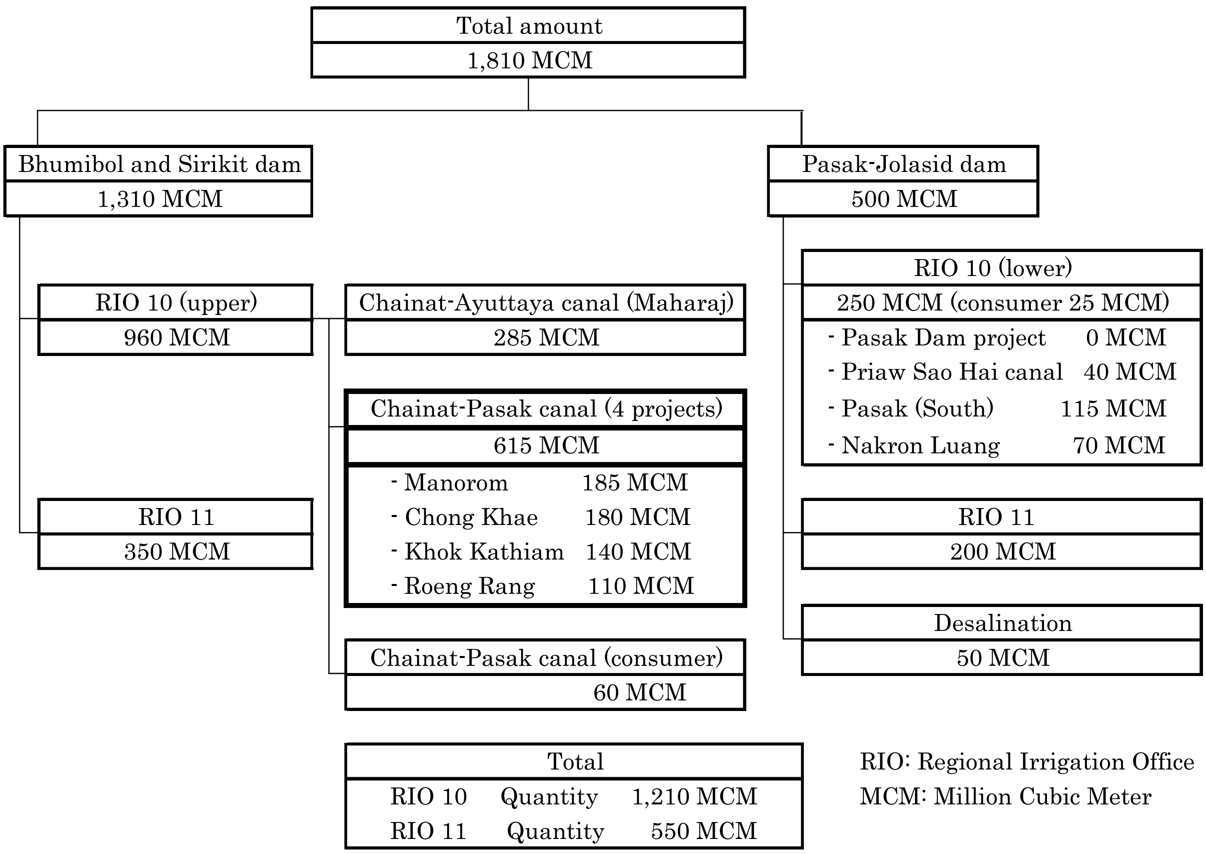


Fig. 3 Water allocation plan for the east bank of the CPD in the 2005 dry season

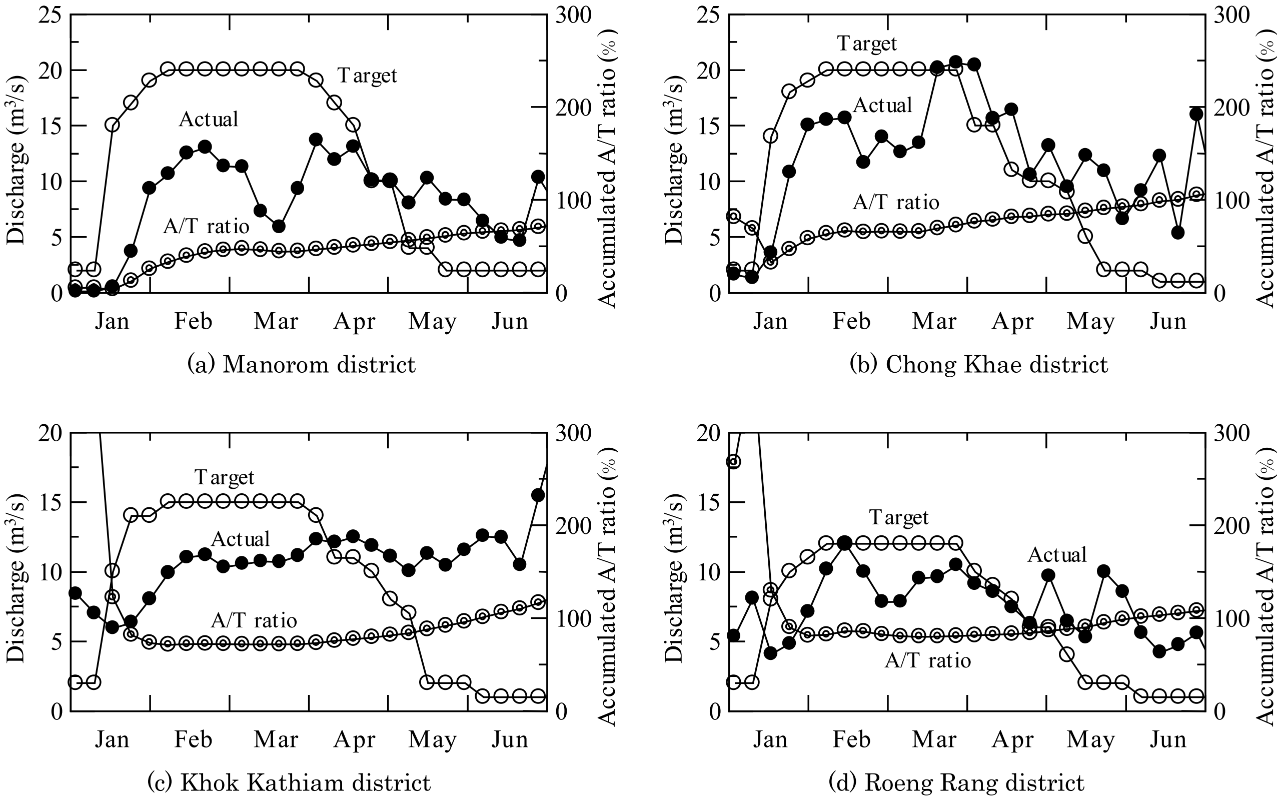


Fig. 4 Target and actual water distribution in the UEB in the 2005 dry season; A/T ratio: the ratio of the amount of actual water distribution to that of the target

Table 3 Seasonal summary of the cultivation and water distribution in the UEB of the Chao Phraya Delta in the 2005 dry season (unit of cultivation area: rai (1 rai = 0.16 ha), unit of discharge: MCM)

O&M office	Manorom	Chong Khae	Khok Kathiam	Roeng Rang
Cultivation, target	87,000	78,000	68,000	49,800
Cultivation, actual	197,158	153,220	105,363	104,170
A/T ratio (%)	227	196	155	209
Discharge, target	185	180	140	110
Discharge, actual	133	193	169	119
A/T ratio (%)	72	107	121	109

Note: "Discharge, actual" is the water supply for the target area. In other words, the target area corresponds to the paddy field depending on water from the lateral canals indicated in **Table 4**.

Table 4 Cultivation area classified by the types of water resources in the UEB of the Chao Phraya delta in the 2005 dry season (unit: rai, 1 rai = 0.16 ha)

O&M office	Manorom	Chong Khae	Khok Kathiam	Roeng Rang
Cultivation, actual	197,158	153,220	105,363	104,170
Lateral canals	102,778	102,910	96,866	67,710
Drainage canals	14,807	50,310	8,497	36,460
Shallow wells	79,573	-	-	-

Note: The rice crop was cultivated two times in some areas; therefore, the area that was supplied water by the lateral canals exceeded the target cultivation area.
Lateral canals: water supply by the RID
Drainage canals: water intake with pumps by farmers
Shallow wells: water intake with pumps by farmers

in the 2005 dry season were 72%, 107%, 121%, and 109%. The problem of unfair water distribution was fairly resolved, and the planned indicator (100% ± 30%) for the water management was achieved.

The seasonal summary of the target and actual cultivation area in the four districts is listed in Table 3. In the four districts, the actual cultivation area was about twice that of the target area; however, the total water supply was almost the same as the planned value. As a matter of fact, the target cultivation area was located in the neighborhood of the lateral canals, and it was the only location where the farmers could receive water. This fact does not explain why the actual cultivation area was so large. Therefore, we categorized the cultivation area into three types based on the types of water resources in Table 4. The characteristics of water use in each of the four districts were satisfactorily clarified by this survey. The table shows that the paddy field that was cultivated by irrigation water supplied from the lateral canals was 20%-40% more than that of the target area, while the remaining paddy fields had other types of water resources. This also implies that the farmers used other water resources such as drainage water for efficiently reusing irrigation water or shallow well water in order to cultivate outside the target area with their own efforts.

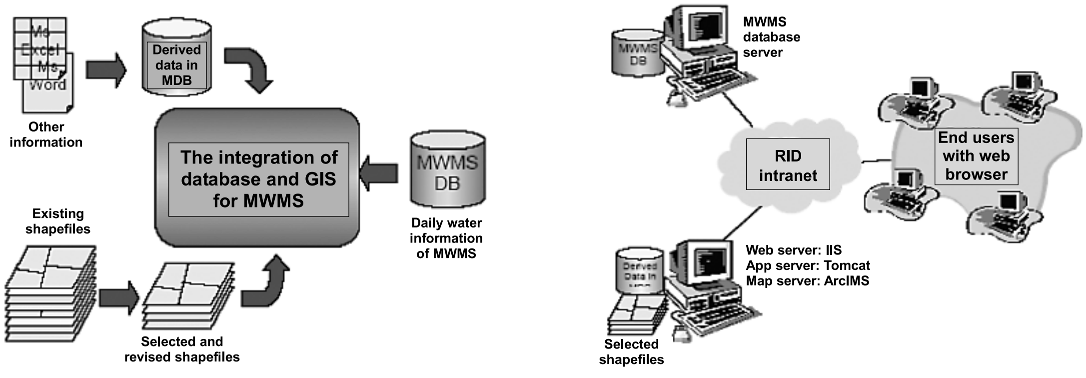
2 Integration of the database and the geographical information system

In order to establish an efficient water management system by developing the DSS, which consists of a database, geographical information system (GIS), and other components, the MWMS Project had thus far developed the database system and the GIS layers separately. However, these systems were still underused because they were too complicated to be used in the daily routine of most of the RID staff. Therefore, as a next step of development, the project aimed to integrate these two systems to make the entire system more user-friendly.

a Overview of the integrated system

It is expected that the "integrated system" will lead to the widespread use of the DSS among the RID staff and contribute to effective water management by sharing necessary data more promptly. The overview of the integrated system is shown in Fig.5. The GIS layers are in the shapefile format and the MWMS database system is based on Microsoft SQL Server. In addition to the database system, information is stored in various formats, such as Microsoft Excel, Microsoft Word, and dBase. Therefore, in order to integrate spatial and non-spatial data, the database design process needs to be revised. This database was designed for integration with the redesigned GIS layers. The sources of the redesigned database are illustrated in Fig.5 (a).

The integration of the GIS layers, the existing database, and other information is the key to success. A web-based GIS application is the solution for integrating these GIS layers and the database system for the users. All users can access the application and database via a web browser in an intranet environment. Users can view all information including both spatial and non-spatial data within the application environment. The software component consists of the web server, application server, and map Server. All the software components are illustrated in Fig.5 (b). The web server used is IIS, which is freeware supplied by Microsoft. The application server for retrieving the database from the web application is Tomcat. ArcIMS (Internet Map Server) is a web-based GIS product that was selected as a tool for the application development of the map server in the project.



(a) Data structure (b) Intranet structure

Fig. 5 Overview of the integrated system

b Specifications

Based on the abovementioned architecture, the integrated system will contain the following specifications: (1) The target area is the UEB; (2) the GIS layers shall be developed in a network version (using ArcIMS); (3) the following components developed by the project shall be utilized for the integrated system: GIS layers on canal networks, hydrology stations, and so on (developed with ArcView); database for O&M data (developed using Microsoft Access and SQL Sever); database for facility information (developed with Microsoft Access); and (4) the above system shall be installed on a server chosen by the project. Furthermore, the GIS layers shall satisfy all the requirements listed in the project.

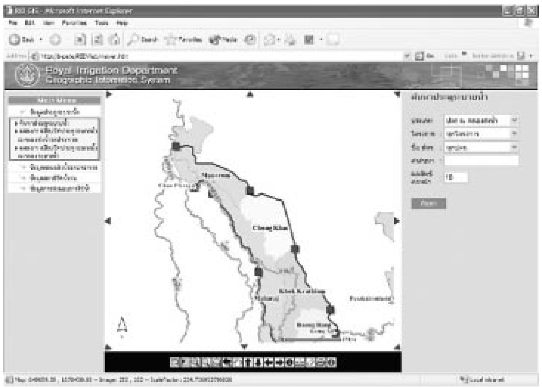


Fig. 6 Graphical user interface of the integrated system

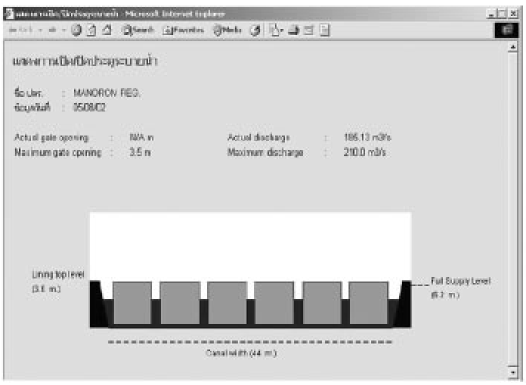
The GIS application is the key to integrating all the data and information in the RID. The application will be deployed via the intranet of the department. All users can access the GIS application and data by using a web browser (see Fig.6). The functionalities of the GIS application are summarized as follows: information on water management and hydrological facilities such as gates, irrigation canals, rainfall observatories, and dams, can be shown, and the information on the above facilities can be searched, displayed, reported, and charted.

c Sample menu

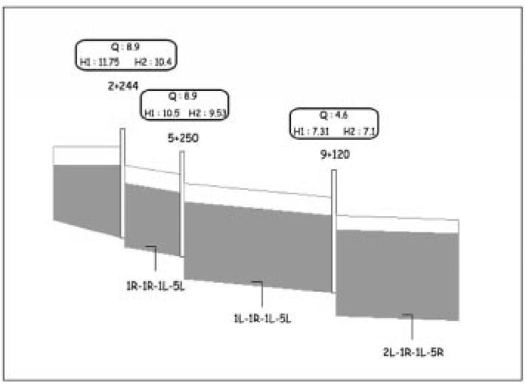
Let us introduce several functions of the integrated system below:

1) Gate condition

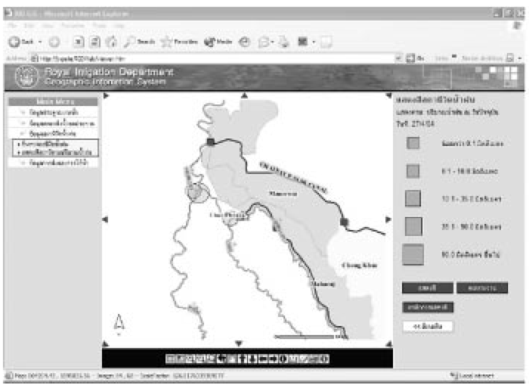
For understanding the gate conditions, the submenu search on the gate information menu is used. From the search result, all the gate names are listed in the data frame view. In order to indicate the opening of a gate of irrigation



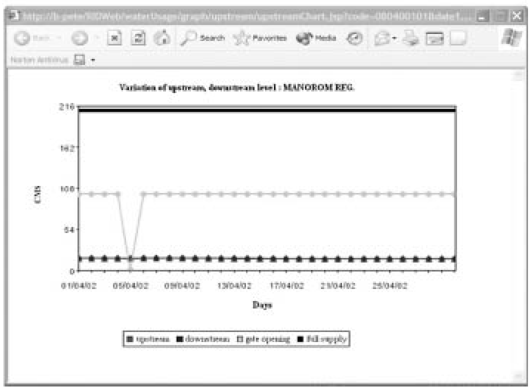
(a) Gate condition



(b) Longitudinal water level



(c) Rainfall stations



(d) Water level of the regulator

Fig. 7 Sample menu of the integrated system canals, the gate is selected by clicking its position on the map. The system displays a message to select the gate on the map. After selection, the system displays a picture of the gate opening, its value, and discharge, as shown in Fig.7 (a).

2) Longitudinal profile of the irrigation canal

The condition of the irrigation canals is obtained by selecting the submenu search on the irrigation canal information menu. After the search, all the irrigation canal names are listed in the data frame view. When the longitudinal profile of an irrigation canal is displayed, the system shows a message for selecting this irrigation canal. After the selection, the system displays the longitudinal profile of the irrigation canal, discharge, and water level, as shown in Fig.7 (b).

3) Report on rainfall measurement stations

In order to search information on rainfall observatories, the submenu search on the rainfall observatory information menu is used. After selecting the submenu search, a search form appears that provides search conditions. From the search results, all the rain observatory names are listed in the data frame view. These names can be clicked to zoom in on each position. Fig.7 (c) shows the rainfall classification at a given time. The system displays a form to define the class value range. We can change the color for each class.

4) Upstream and downstream water level of the regulator

To observe the information on irrigation, the submenu on the water supply and water use information menu is used. The functions are classified into three types: (1) upstream and downstream water level and gate opening of the regulator, (2) discharge through the regulator, and (3) ratio between the actual discharge and the planned value. Fig.7 (d) is a sample figure for the first type.

In addition to these functions, there are many useful functions in this system; however, the most important task for advanced water management is to develop these hydrological and hydraulic databases and improve the accuracy of data collection.

3 Runoff from the left bank of the Chainat-Pasak main canal (Sucharit et al., 2005)

In this analysis, surplus water in the rainy season, particularly during periods of flood, is estimated in order to save water that can be used in the dry season. The left bank of the Chainat-Pasak main canal was selected for hydrological analysis to evaluate the runoff volume, which overflowed into the canal in the area. To be specific, we reviewed the hydrological data, understood the runoff characteristics, estimated the runoff ratio, and recommended further applications and works.

a Study area

The study area covered the left bank of the Chainat-Pasak main canal between the Chong Khae and the Khok Kathiam regulator, as shown in Fig.8. For the analysis, daily rainfall data from 1994 to 2004 at 14 sta-

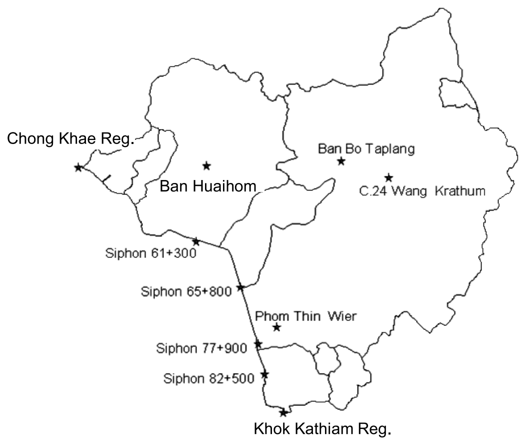


Fig. 8 Study area for runoff analysis

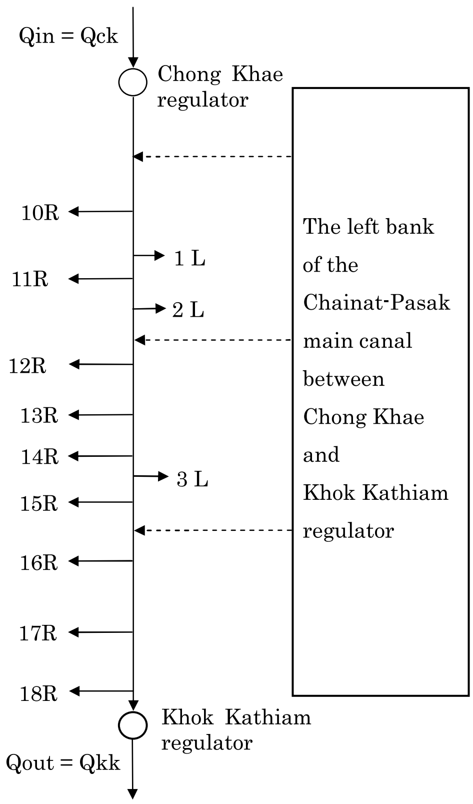


Fig. 9 Water balance

tions in the area were used. The discharge through the Chong Khae and the Khok Kathiam regulator from 1994 to 2004 was also considered.

To understand the runoff mechanism, three sites-Ban Huaihom, Ban Bo Taplang, and Phom Thin-were selected based on the soil type data. The rainfall, groundwater level, and soil moisture were observed in the rainy season from 2003 to 2004.

In addition, we also measured the water level and discharge at the drainage canals. In the study area, the water level is measured at six sites including the above three sites. Just outside the study area, the outflow discharge from the study area was measured at the siphons shown in Fig.8.

b Schematization of water balance

The water flow schematization is shown in Fig.9. The inflow water from the Chong Khae regulator passes through the Chainat-Pasak canal, and flows out through the Khok Kathiam regulator. In the section, the inflow water is divided into the irrigation area passing thorough the lateral canals, and receives runoff from the eastern watershed. Based on the water balance concept, the runoff volume was estimated from the difference in the inflow and outflow as shown in Fig.9, while the drained water from the canal was determined by the recorded data or assumed to be small during this period. The flow through the regulator was calculated from the gate formula for free flow or submerged flow.

c Typical rainfall-runoff pattern

The runoff pattern was analyzed by using only relevant, that is, well-correlated rainfall-runoff events to observe the average rainfall duration, minimum rainfall amount that induced runoff, average lag time between rainfall and runoff, and average runoff duration. The monthly rainfall-runoff patterns showed that the rainfall, which induced runoff, had a duration of 5 to 8 days with a minimum accumulated rainfall of 10 to 20 mm, and the runoff duration was 3 to 5 days. The runoff started from two days before the end of rainfall at the earliest, and one day after the end of rainfall at the latest.

d Monthly runoff ratio and event-based runoff ratio

In this analysis, two types of runoff ratios are used to analyze the relationship between runoff volume and rainfall. The monthly runoff ratio is derived from the monthly runoff volume divided by the monthly rainfall in the catchment area. To calculate the event based runoff ratio, the runoff data of each event is divided by the rainfall amount of that event.

For water planning, the long term monthly data can be used for estimating the runoff discharge from the study area. The analysis was conducted by considering two cases: in the first case, the entire monthly runoff data is used for the monthly runoff ratio, and in the second case, only runoff data with a good correlation are used. In the first case, the relationship between the runoff ratio and the cumulative rainfall during the rainy season is represented in the exponential form. In the second case, this relationship is classified into two types with a high rainfall ratio and low ratio. The study shows that the monthly runoff ratio of the first case and that of the second case range between 0.01-0.24 and 0.01-0.06, respectively.

In actual application, the estimation of runoff is usually based on the actual rainfall event. The event-based runoff ratio depended on the rainfall pattern and was classified into two types: (1) the ratio is less than 0.03 when the rain spell exceeded 3-4 days or there was no rainfall for 3-4 days and (2) the ratio is considerably higher when there was continuous rain before the runoff, that is, the soil moisture was high. The average event-based runoff ratio in July, August, September, and October was 0.10, 0.04, 0.06, and 0.09, respectively.

e Relation between rainfall, groundwater level, soil moisture, and runoff

During field monitoring, the rainfall data, runoff in the nearby canal, soil moisture, and shallow groundwater level data were collected. Fig.10 indicates the result at Ban Huaihom. In general, the soil moisture differed significantly between the rainy season and the dry season. The soil became wet after rainfall but returned to the dry state after a few weeks without rain. The shallow groundwater level remained fairly constant. Due to the considerable dry spell in the years 2003 and 2004, the runoff pattern could be monitored only in September 2004 at Ban Huaihom station, while no runoff was found at the other stations due to high infiltration. This indicated a high runoff interception and a canal storage effect in the area, which is rain-fed agricultural land, where only a certain amount of continuous rainfall can

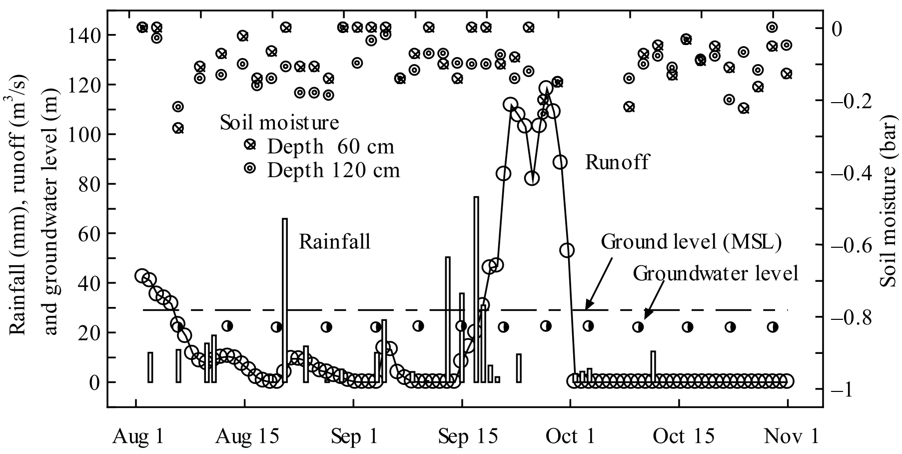


Fig. 10 Relation between rainfall, groundwater level, soil moisture, and runoff at Ban Huaihom

induce runoff from the area. In this analysis, the rainfall-runoff relationships derived from the study were based on the selected and available data. In order to derive more accurate relationships, further data collection is needed, and past unmatched data should be reviewed.

4 Water balance in the UEB of the CPD

The purpose of this activity is to construct the water balance model and clarify the characteristics of water balance in the UEB. The available amount of irrigation water in the dry season is examined by saving irrigation water in the rainy season and storing it in the dams. As a result, the cropping area, which can be increased in the dry season, is estimated.

a Water supply condition of the basin

Firstly, the water balance between the Manorom and Roeng Rang regulators in the Chainat-Pasak main canal is examined. Fig.11 shows the comparison between the total water supply to the lateral canals and the difference in the discharge between the Manorom and the Roeng Rang regulator for eight years. The difference between the two regulators should be equal to the total intake volume of the lateral canals; however, the former value is always higher than the latter value. This implies that either the intake volume of the lateral canals was estimated to be too low, or there was a deficiency in the measurement. In the following analysis, the difference in discharge between the two regulators was regarded as the total water supply volume to the UEB because the results of measurement at the main facilities

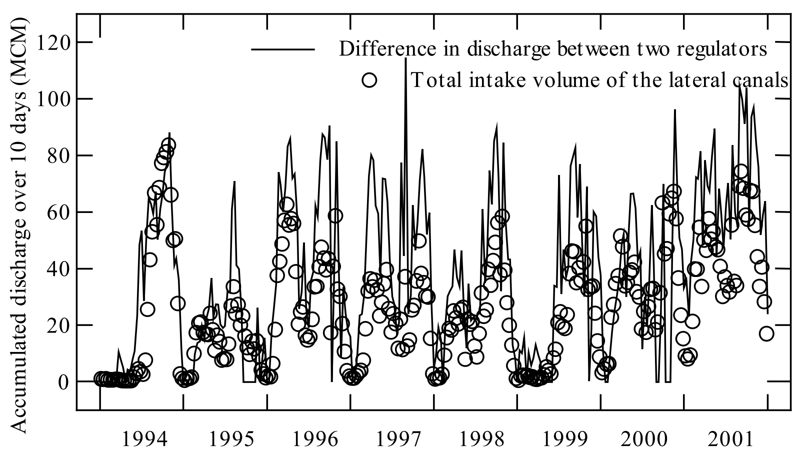


Fig. 11 Comparison of the difference in discharge between the Manorom and Roeng Rang regulators with the total intake volume of the lateral canals

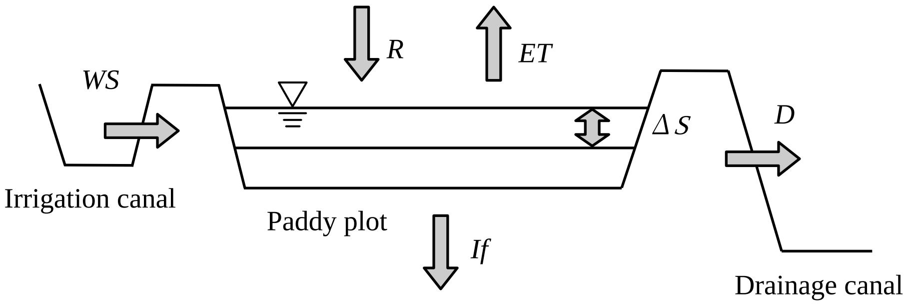


Fig. 12 Water balance model for a paddy plot

are more reliable than the summation of the intake volume at many small facilities. In addition, the total intake discharge at the lateral canals could be lower than the difference between the regulators because the RID sometimes did not detect the discharge of pumps introduced by farmers. When the total water supply to the lateral canals exceeded the difference, this supply was regarded to be the total water supply volume to the UEB.

Next, we examined the water management situation in the basin. When we observe the relation between the area rainfall and the water supply in the rainy season, is found that the water supply is related to the rainfall. Further, we can speculate that the water manager utilizes the rainfall efficiently. In particular, the water supply declined gradually after the 1990s, and water management has been improving in the UEB.

b Water balance model

The relation between the actual cropping area and the water supply in the dry season indicated that the water supply was strongly associated with the actual cropping area. Therefore, in this analysis, it is extremely important to construct an appropriate water balance model for a paddy plot. Meanwhile, it was necessary for us to design a model that was as simple as possible and allowed the execution of the calculation on a spreadsheet. This would enable the use of the water balance model by the RID staff without any difficulty.

Water balance model for a paddy plot is described as follows:

$$\Delta S = R + WS - ET - If - D \quad (1)$$

Here, ΔS is the difference of the storage in the paddy plot between the time stage $t = t_1$ and t_2; R, the rainfall; WS, the water supply; ET, the evapotranspiration; If, the infiltration; and D, the drainage. The schematization of the model is shown as Fig.12. When the initial storage is given at the time stage $t = t_1$, WS and D are calculated based on the relational expression between S, WS_1, and D. Next, R, ET, and If is substituted in equation (1), then S at the next time stage $t = t_2$ is calculated.

For the calculation of WS and D we introduce the concept of the maximum water level (MWL) and target water level (TWL). If the water level in the paddy plot is higher than the MWL, the drainage discharge is calculated without any water supply. If it is lower than the MWL and higher than the TWL, there is no water supply and drainage. Lastly, if it is lower than the TWL, the water supply is calculated without drainage.

c Results of water balance analysis

In order to estimate the compatibility of the calculated water balance with the actual value, the calculated water supply and the observed value in the target area were compared, as shown in Fig.13. It can be stated that the compatibility is quite satisfactory; however, there are several aspects that should be improved upon. For instance, the influence of floods and the inflow from outside the target area should be estimated, and the transformation of the cropping pattern should be considered. Nevertheless, the analysis showed that the estimated irrigation efficiency gradually improved for these 25 years, and its value increased from 0.6 to 0.8. Unless we consider the effect of the influence of floods and the inflow from outside the target area, the estimated irrigation efficiency will be less than the abovementioned values.

Lastly, let us introduce the effect of savings of irrigation water in the rainy season. This effect represents the possible increase in the irrigable area during the dry season when the irrigation water in the rainy season is saved. When we assume the operation method of reservoirs and regulators in the Chao Phraya river basin based on the interviews with the operators of the facilities, we can calculate the water balance between the reservoirs and the target area. According to this analysis, the volume of available water generated due to practical water management in the rainy

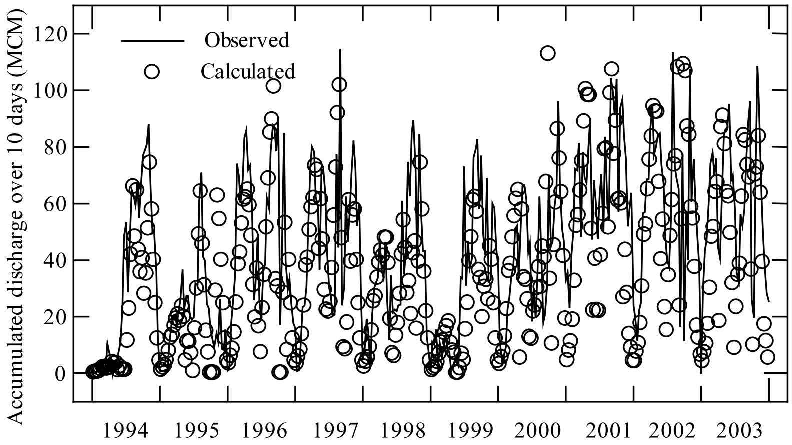


Fig. 13 Results of water balance analysis

season was calculated. In other words, in the case of 10% reduction in the rainy season water supply, half the reduction amount is converted to the increase in the reservoir storage, and the dry season cropping area can be increased by 10%.

V Recommendations

In order to further advance the modernization of the water management system in the CPD, we made the following recommendations to the RID.

1) The integrated system of the GIS and the database was developed as a part of the DSS for water management; however, the maintenance and updating of the contents seems to be insufficient. Because the water management data are distributed to the RID headquarters every day, the key contents should be updated without any delay. It is also essential to enhance the old databases.

2) During the 2004 dry season, the WARC was newly organized by the staff of the RID headquarters, the RIO 10, and the four O&M offices along the Chainat-Pasak main canal. Each O&M office could share their problems and discuss solutions at the monthly WARC meeting. The benefit of the WARC meeting was understood by the members; therefore, they should continue the monthly meetings and attempt to extend this system to other regions.

3) In order to promote the effective use of water, a runoff analysis in the left bank of the Chainat-Pasak main canal and water balance analysis in the UEB were conducted. Some useful results were obtained from these analyses; however, the accuracy of the compiled data or the amount of necessary data was not sufficient. In order to increase the reliability of the analysis, further data collection and analysis are recommended.

4) For the modernization of the water management, it is essential to collect accurate data. In this sense, the water management data collected by the RID on a daily basis are very important. The following proposals derived from the activities of the MWMS Project should be focused on:

(i) Revision of the discharge calibration curves for the regulators in the main canal and the intake gates at the lateral canals: The difference in discharge between the regulators in the Chainat-Pasak main canal should be identical to the results of the summation of water distribution to the lateral canals between these regulators. However, in reality, there existed a significant difference. This implies that the discharge calibration curves of the regulators or the intake gates differ from the actual condition.

(ii) Acquisition of water management data at the important main canals: The data on water distribution to the lateral canals are not obtained along the Chainat-Ayuttaya main canal. This implies that the reasonable planning of water allocation and water distribution according to the plan becomes difficult. Further, it is necessary to obtain the value of discharge through the important drainage regulators in order to precisely understand the water balance of the district in the future.

(iii) Response for the rehabilitation of decrepit facilities: If the intake facilities become decrepit or the lateral canals are rehabilitated, a revision of the discharge calibration curves at the intake mouth is needed. The MWMS Project revised the discharge calibration curve at the 23R, 24R, and 25R lateral canals in the Roeng Rang district because the estimated discharge appeared to be significantly different from the actual condition.

(iv) Estimation of discharge through a siphon: The discharge through a siphon installed in the Chainat-Pasak main canal could not be estimated because the discharge calibration curve appears scattered and dumped. It is necessary to know the amount of inflow water from the outside to the UEB in order to estimate the water balance of the region.

5) The typical cropping pattern proposed by the RID differs significantly from the actual one. This results in a difference between the water allocation plan and the actual water distribution. In the follow-up program, the ratio of the actual water distribution to the planned value with regard to the total amount in the dry season was regulated within a range of 100% ± 30% in each of the four districts along the Chainat-Pasak main canal; however, it was difficult to prevent farmers along the main canal from setting pumps and taking water arbitrarily. In Thailand, there is no way to enforce strict regulations because there are no laws on water rights. Therefore, the farmers do not follow the plan and take water arbitrarily. Under the present situation, we recommend that the RID should strengthen the farmers' organizations and educate farmers on water use; however, the development of legal systems will be required in the near future.

VI Conclusions

The authors played a leading role in the activities for the basin and delta level water management in the follow-up program of the MWMS Project. In particular, the JICA experts, Takaki and Shioda, routinely monitored the planning process of water allocation in the UEB of the CPD so that the dry-season water allocation plan was prepared without any delay. Further, two authors of this paper attended the monthly water allocation regulating committee meeting, understood the cropping situation and the actual water distribution in the UEB, and provided appropriate advice on the water allocation policy to the RID staff in order to achieve the objectives of water management.

For water management, the MWMS Project has introduced the telemetry system, a data communication system, a database, and a geographical information system as the DSS. Further, the integrated system composed of the database and the geographical information system was launched in the follow-up program. In addition, the runoff and water balance analyses for efficient water use were conducted based on the stored data. As mentioned above, the decision support system has been upgraded with regard to hardware and software. However, the final decision on water management must be arrived at by the RID staff themselves. In other words, the staff should consider refining their skills in order to combine the system with decision making for water management, even if the developed system is progressive and advanced.

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チャオプラヤデルタ上流東岸域における水管理システムの近代化に向けて

―タイ国水管理システム近代化計画のフォローアップ活動―

高木強治*，塩田克郎**, ARULVIJITSKUL Pongsak***, KOONTANAKULVONG Sucharit****, 堀川直紀*****, PUNYACHOM Athaporn*** and BUDDHAPALIT Atthaporn***

要　約

本報文は，国際協力機構の技術協力プロジェクト・タイ国水管理システム近代化計画フォローアップ（2004年４月～2005年９月）における流域デルタレベル水管理分野の活動報告である。技術指導の内容は，乾期配水計画策定に関する助言，配水実態のモニターと配水調整の指導，水管理意思決定支援システムの開発，および水資源の有効利用に資する流出解析と水収支解析の実施であった。

特に，チャイナートパサック幹線水路沿いの４つの維持管理事務所が所管する灌漑地区の不公平な配水を是正するため，2004年の乾期から，タイ国王室灌漑局本部，第10地方灌漑事務所（上述の４つの維持管理事務所を統括），および維持管理事務所職員からなる配水調整委員会を組織した。配水調整委員会では，乾期の配水計画と実績が毎月議論され，その議論の結果は，その後の配水方針に反映された。この結果，2005年の乾期，４つの維持管理事務所における総配水量の実績値と計画値の比は，上流からそれぞれ72, 107, 121および109%となり，チャイナートパサック幹線水路掛かりにおける，公平な乾期配水が達成された。

また，水管理意思決定支援システムの一部となる地理情報システムとデータベースの統合システムを開発し，水管理担当職員の業務の効率化を図った。さらに，カウンターパートを指導して水理・水文観測を実施し，大学や国際協力機構派遣の短期専門家と連携して，流出解析や水収支解析を行い，対象流域における利用可能な水資源の評価を行った。

*水工部水環境保全研究室
** 財団法人日本水土総合研究所
*** タイ国王室灌漑局
**** チュラロンコーン大学水資源工学部
***** 農地整備部用水管理研究室

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