チャオプラヤデルタ上流東岸域における水管理計画・運用

〔農工研技報 203
155～193，2005〕

Water Management Planning and Operation in the Upper East Bank of the Chao Phraya Delta

UEDA Tatsuki*, OGAWA Shigeo**, SHIODA Katsuro***, ARULVIJITSKUL Pongsak****, KLINKHACHORN Phonchai****, CHOMPRADIT Chatchom**** and PUNYACHOM Athaporn****

Contents

*Laboratory of Upland Field, Department of Agricultural Environment Engineering
**Laboratory of Rural Land Resources, Department of Regional Resources
***The Modernization of Water Management System Project in Thailand
****Royal Irrigation Department, the Government of Thailand
Received February, 4, 2005
Keywords: Chao Phraya Delta, hydrology, irrigation, paddy field, remote sensing, Thailand, water management

Abbreviations

C-A	Chainat-Ayutthaya main canal
C-P	Chainat-Pasak main canal
EGAT	Electricity Generating Authority of Thailand
MCM	Million Cubic Meter
MWMS Project	The Modernization of Water Management System Project in Thailand
RID	Royal Irrigation Department, the Ministry of Agriculture and Cooperatives
RIO	Regional Irrigation Office of RID
UEB	Upper East Bank (of the Chao Phraya Delta)

Notes

1) "Rai" is an aerial unit widely used in Thailand and equals with 0.16 hectare. In this study, authors mostly showed aerial units in ha, but some sentences concurrently employed "rai" to follow the Thai custom.
2) Within Royal Irrigation Department (RID), a local branch organization which is in charge of operation and maintenance of irrigation and drainage facilities is called "O&M Project Office", "Project Office" or "Project".
3) RID generally defines the "dry season" as from January to June and the "rainy season" as from July to December. This study will follow this definition.

I Introduction

1 Background of the MWMS Project and the present study

The Chao Phraya Delta, where rice cultivation has been practiced extensively as the national granary and which holds the capital Bangkok in the downstream, is the heart of economic activities in Thailand.

In recent years, the water demand has been growing due to the migration of people into Bangkok and its surroundings, an increase of foreign capital factories following the industrialization, and the expansion of dry-season's rice cultivation (Kaida, 1978; Shioda, 2000). But the water supply in this region largely depends upon the Bhumibol and Sirikit Reservoir Dams located in the upstream of the Chao Phraya River (Fig. 1 and Table 1). Therefore, the water supply conditions are increasingly becoming vulnerable to the weather conditions.

On the other hand, developing new large-scale reservoirs is becoming difficult, as the consideration of environmental effects and discussions with landowners have become important issues. Thus any new water resources development project needs a long period of coordination in recent years. Furthermore, the agricultural sector that occupies a large part of water demand has such problems as the shortage of irrigation water in the dry seasons and inefficient use of irrigation water at the on-farm level.

Thus, in order to cope with the new water demand, the government of Thailand has aimed at using existing water resources more effectively through employing the modernized water management system such as the improved irrigation facilities and water management technology.

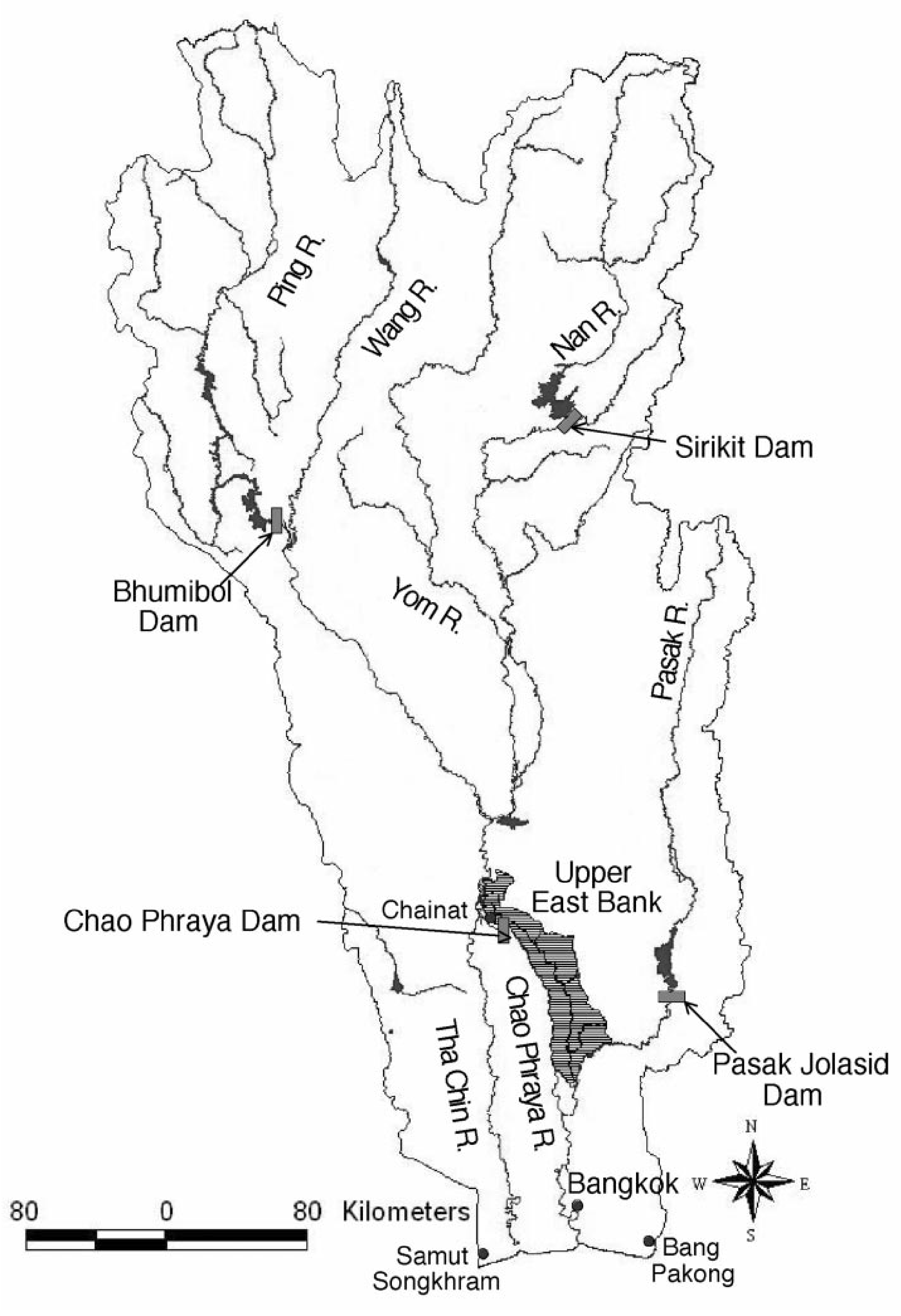


Fig. 1 Outline of the Chao Phraya River basin

The Chao Phraya Delta roughly corresponds with a triangle connecting Chainat, Samut Songkhram, and Bang Pakong.

Table 1 Basic facts concerning the Chao Phraya River Basin and the Upper East Bank of the Chao Phraya Delta

Major reservoir and diversion dams			
Name	Maximum storage	Construction years	Operation year
Chao Phraya diversion dam	-	1952-57	1957
Bhumibol dam	13,500 MCM	1958-64	1964
Sirikit dam	9,500 MCM	1963-72	1974
Pasak Jolasid dam	780 MCM	1994-99	1999

Areas of the basin, delta and Projects	
Catchment area of the Chao Phraya River	162,000 km^2
Total area of the Chao Phraya Delta	13,400 km^2 (1,340,000 ha)
Greater Chao Phraya Project	Irrigable area: 497,850 ha
Upper East Bank (UEB) of the Chao Phraya Delta	Total area: 244,000 ha Irrigable area: 218,000 ha
Manorom O&M Project Office	Project area: 45,730 ha Irrigable area: 41,970 ha
Chong Khae O&M Project Office	Project area: 45,060 ha Irrigable area: 38,200 ha
Khok Krathiam O&M Project Office	Project area: 36,530 ha Irrigable area: 32,880 ha
Roeng Rang O&M Project Office	Project area: 30,220 ha Irrigable area: 28,640 ha
Maharaj O&M Project Office	Project area: 83,830 ha Irrigable area: 76,210 ha

Irrigation canals in the Upper East Bank			
Name	Max. discharge	Length	Irrigable area
Chainat-Pasak Main Irrigation Canal	210 m^3/s	134 km	125,410 ha
Chainat-Ayutthaya Main Irrigation Canal	75 m^3/s	120 km	76,210 ha
18R lateral irrigation canal*	6.8 m^3/s	9.972 km	2,560 ha

Note: MCM: Million Cubic Meter.

*A command area of the 18R lateral irrigation canal is the Model Area of the MWMS Project, especially the activities at the on-farm level (see Fig. 2).

Furthermore, the recent government policy, according to the 8th Agricultural Development Plan (1997 to 2001), is to strengthen an international competitive position through the production of highly-valued and diversified crops and effective utilization of the natural resources for sustainable agricultural development. As the largest rice exporting country in the world, the Thai government intends to stop further decrease in the price of rice that is under the surplus condition in the international market. At the same time, the government intends to secure the farmers' income and to promote the crop diversification instead of rice monoculture during the water shortage period of dry-seasons.

In summary, we need to promote effective water management methods and crop diversification, as the counter-measure to the water shortage in the dry season and decrease in rice price.

From the above backgrounds, the government of the Kingdom of Thailand requested a new project under the Project Type of Technical Cooperation scheme to the government of Japan, who has implemented the Irrigation Engineering Center Project (IEC and IEC Phase II) from 1985 to 1997. Accordingly, both the governments agreed to launch a new Technical Cooperation Project called the "Modernization of Water Management System (MWMS) Project".

The objectives of the MWMS Project are overviewed as follows. The improvement of water management at the basin and delta level is implemented for creating water resources. At the same time, the improvement of on-farm facilities for dry-season's cropping is executed. And for maintaining the installed facilities and improving water management at the on-farm level, Water Users' Groups organized by the farmers are established and strengthened. In addition, farming technologies for dry-season's field cropping in the delta area are developed and promoted. And, for the dissemination of the above outputs and advancement of relevant activities, trainings and seminars are conducted.

The Project is undertaken by the Royal Irrigation Department (RID) and the Department of Agriculture Extension (DOAE) with the technical assistance from the Japan International Cooperation Agency (JICA). The Project is planned to continue for 5 years from April 1999 to March 2004, with a follow-up program from April 2004 to September 2005.

Among the five Working Groups organized under the MWMS Project, the Basin and Delta Level Water Management Working Group, to which the authors belonged, was engaged in improving basin and delta level water management systems. Since 2002, the Working Group focused attentions to the Upper East Bank of the Chao Phraya Delta, where we set a study area. Thus, this study summarized major activities and outcomes of the Working Group between April 2002 and March 2004, with the focus on water management planning and operation in the Upper East Bank of the Chao Phraya Delta.

The authors express our sincere gratitude to Mr. Virat Khao-uppatum, Mr. Theerawat Tangpanich and Mr. Paopong Kararum, the former and present Project Managers of the MWMS Project, for their support for conducting this study. We are also grateful to: Mr. Tanasak Taptone, Mr. Somkid Sapaokham and Mr. Sompob Intaraksa who contributed in making GIS layers and analyzing satellite images; Mr. Somnuk Jirasirisopon for developing the digital data report system; Mr. Pornchai Ponchour and Mr. Sombat Sontisri who assisted in collecting water management data from local offices; and Mr. Apichai Wattanayomnaporn and 5 Project Offices in the UEB area for providing useful information.

2 Outline of the study area

The model area of this study is set on the Upper East Bank (UEB) of the Chao Phraya Delta (Fig. 2). The UEB area occupies an area of 244,000 ha (Table 1), whose borders are the Chao Phraya River on the west, the Chainat-Pasak Canal on the east, and the Pasak River on the south. The UEB area roughly corresponds to the command areas of Maharaj, Manorom, Chong Khae, Khok Kathiam and Roeng Rang O&M Project Offices, all of which are under the responsibility of the Regional Irrigation Office 10 (RIO-10) of RID. Main water sources for the area are the Chainat-Pasak and the Chainat-Ayutthaya main canals, both of which intake water from the Chao Phraya River through main regulators located upstream of the Chao Phraya Dam (Fig. 2 and Table 1). Main water sources for the above two main canals are Bhumibol and Sirikit reservoir dams (Fig. 1), both of which are located in the upper Chao Phraya River Basin.

The Chainat-Pasak canal has four main regulators across the canal (Fig. 2): Manorom regulator intakes water from the Chao Phraya River, while Chong Khae, Khok Kathiam and Roeng Rang regulators raise the upstream water levels so that lateral canals could intake water by gravity. Some lateral canals, however, have higher sill elevations at the heads than the water levels in the Chainat-Pasak canal. Therefore such lateral canals employ either mobile or stationary pumping devices at the canal heads for supplying water to the command area when the water level in the Chainat-Pasak canal is low. Along the Chainat-Pasak canal, 1R, 2R, 3R-2 and 25R lateral canals (Fig. 2) have such stationary pumping houses at the heads. In addition, Manorom Project has five canals with stationary pumping houses, namely Khao Kaeo, Ban Lek, Tha Chanuan, Wat Khok and Thammamun (Fig. 2), which intake water directly from the Chao Phraya River. Those stationary pumping houses are operated with electrical pumps.

II Trends in water management and cultivation in recent years

1 Introduction

The Basin and Delta Level Water Management Working Group has been digitizing the water level and discharge data from 1987 to the present at the main regulators and some relevant cultivation data in the Upper East Bank (UEB) of the Chao Phraya Delta. By employing these data, this section aims to summarize the trend in water allocation and cultivation since 1987 within the UEB area.

2 Materials and methods

a Water management data

The monthly data of water storage volume at Bhumibol and Sirikit dams were obtained from the Water Allocation Group at RID Head Office. The daily water-level and discharge data from 1987 to the present at the main regulators in the UEB area, namely Maharaj, Manorom, Chong Khae, Khok Kathiam and Roeng Rang regulators, were obtained from the Regional Irrigation Office 10 (RIO-10), RID. However Maharaj regulator had the data since 1994 only. These daily data were summarized into monthly and seasonal cumulative figures using the "database menu application" developed by the Working Group.

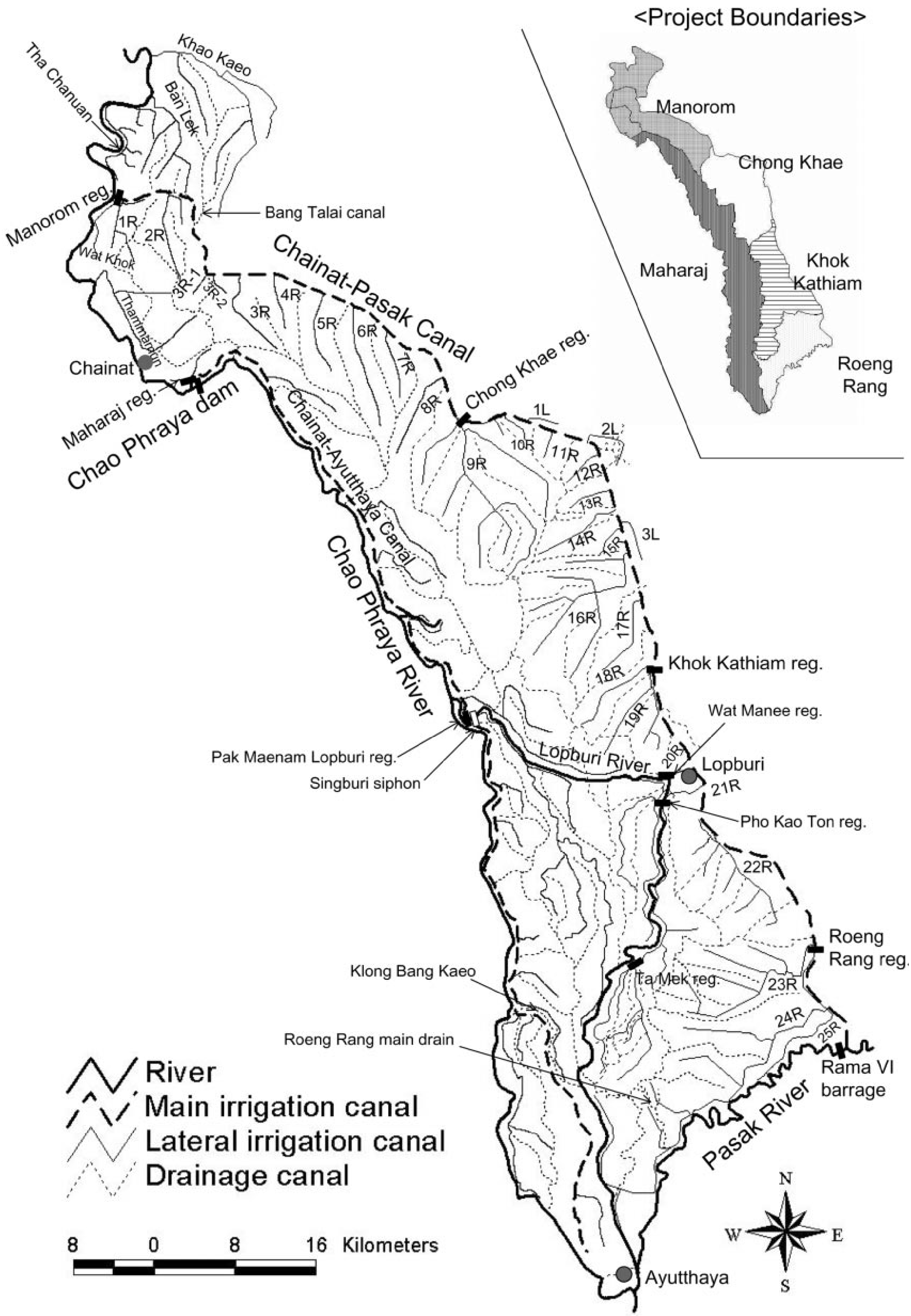


Fig. 2 Outline of the Upper East Bank of the Chao Phraya Delta

The UEB area was divided into two areas in terms of the main canal systems: (1) the Chainat-Pasak main canal (C-P) area comprising Manorom, Chong Khae, Khok Kathiam and Roeng Rang Projects; and (2) the Chainat-Ayutthaya main canal (C-A) area comprising Maharaj Project. The discharges allocated to these two areas were estimated using the following equations:

$$Q_{C\text{-}P} = (Q_{MN} - Q_{RR} + Q_p) \times f \quad (1)$$

$$Q_{C\text{-}A} = Q_{MJ} \times f \quad (2)$$

Where: $Q_{C\text{-}P}$ is a discharge allocated to the command of Chainat-Pasak canal (C-P area);

$Q_{C\text{-}A}$ is a discharge allocated to the command of Chainat-Ayutthaya canal (C-A area);

Q_{MN} is a discharge at Manorom regulator;

Q_{RR} is a discharge at Roeng Rang regulator;

Q_p is a sum of discharges pumped at 5 pump stations along the Chao Phraya River (Manorom Project), and lateral canal heads of 24R and 25R;

Q_{MJ} is a discharge at Maharaj regulator; and

f is a correction factor for sectors excluding agriculture. The factors f for the C-P and C-A areas are assumed to be 0.92 and 0.94 respectively (see the text below).

The discharges at Manorom, Roeng Rang, and Maharaj regulators were drawn from the actual records. The discharges at the 5 pump stations in Manorom Project, and 24R and 25R pump stations were estimated from the average of the available 1994-1996 records, and added to the discharge allocated to the C-P area. This was because these pump stations took water from either directly from the Chao Phraya River or from the downstream of Roeng Rang regulator (Fig. 2). Meanwhile the discharge allocated to the C-A area was assumed to be equal to the intake discharge at Maharaj regulator, because this regulator was the only major water source for the C-A area.

The irrigation canals in the UEB area distribute water not only to agriculture, but also to other sectors such as municipal waterworks and some institutions. Because the amount of water allocated to such sectors would not change very much, an assumption was made that these sectors would constantly consume 8% of the total allocated water in the C-P area and 6% in the C-A area, as stated in the water allocation plan for the dry season 2002. This assumption contributes for the factor f in the above equations (1) and (2).

b Cultivation data

The data on cultivation areas of dry-season rice were obtained from the RIO-10, and those of rainy-season rice and other crops from the Irrigated Agriculture Division, RID Head Office. As for the rainy season, only the data of rice paddy were available. RID defined the rainy season as from July to December and the dry season as from January to June, although this definition inevitably incurred some discrepancies from the actual complex cropping patterns in the UEB area. Nevertheless, the present study would follow this definition for simplicity.

The cultivation data were categorized into rice, crop/vegetable, fruit/tree and fishpond. The crop/vegetable category includes vegetables and such field crops as sweet potato, potato, tobacco, beans, sunflower, millet, corn, cassava, and so on. The fruit/tree category includes fruit crops and perennial trees for timbers etc. According to the RIO-10, the unit water demands for each crop category were assumed as 2000 (m^3/rai/season) for rice, 1400 for fruit/tree, and 1000 each for crop/vegetable and fishpond. In accordance with the above assumptions, therefore, the total cultivation area of all crops was converted to the "rice equivalent area" with the following equation:

$$A_{RE} = A_R \times 1.0 + A_{CV} \times 0.5 + A_{FT} \times 0.7 + A_P \times 0.5 \quad (3)$$

Where: A_{RE} is a rice equivalent area;

A_R is a rice area;

A_{CV} is a crop/vegetable area;

A_{FT} is a fruit/tree area; and

A_P is a fishpond area.

c Questionnaire survey

Each Project area is divided into several "zones", in which irrigation and drainage facilities are maintained and operated by a so-called "zone-man" who is an employee of RID. In May 2003, a questionnaire survey was conducted to the zone-men within the UEB area in order to count the number of shallow wells in each zone. They were asked to exclude small hand pumps for domestic uses when counting the shallow wells.

3 Trends in water uses

a Water storage at the upstream dams

Figs. 3 and 4 show trends in the total volume of water storage, inflow and release volumes at the Bhumibol and Sirikit dams (Fig. 1), which are the main water sources for water-use activities in the Chao Phraya Delta. It is clearly indicated that the first half of the 1990s, and 1999, experienced water shortage due to the scarce rainfall in the previous rainy season etc., whilst after 2000, the dams enjoyed moderate or plenty storage of water available for the dry seasons. This trend was reflected in the release discharges from the two dams during the dry season (Fig. 4), and affected the water management and cultivation in the Delta as mentioned in the following sections.

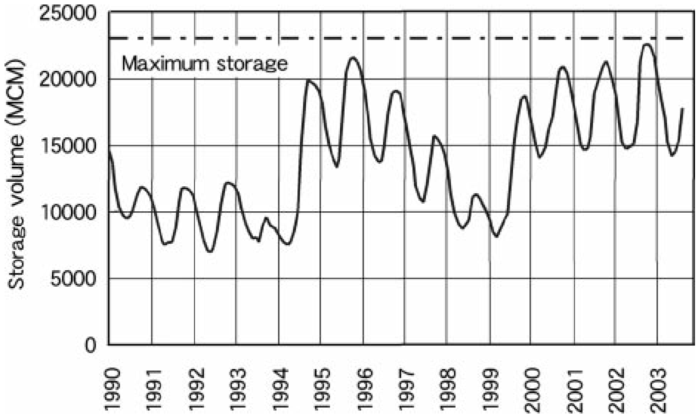
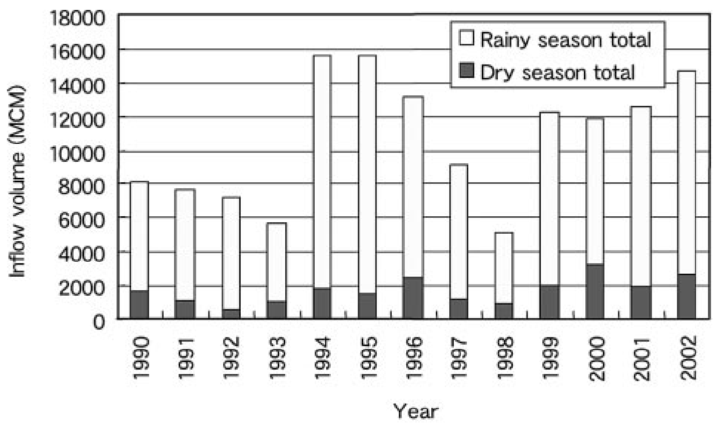


Fig. 3 Total volume of water storage at the Bhumibol and Sirikit dams



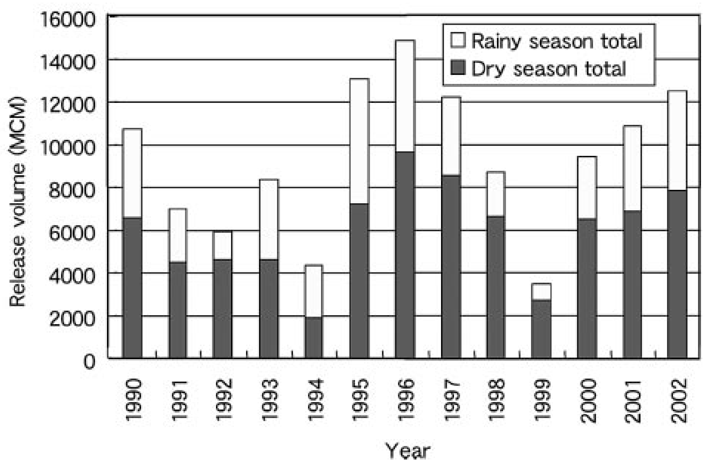
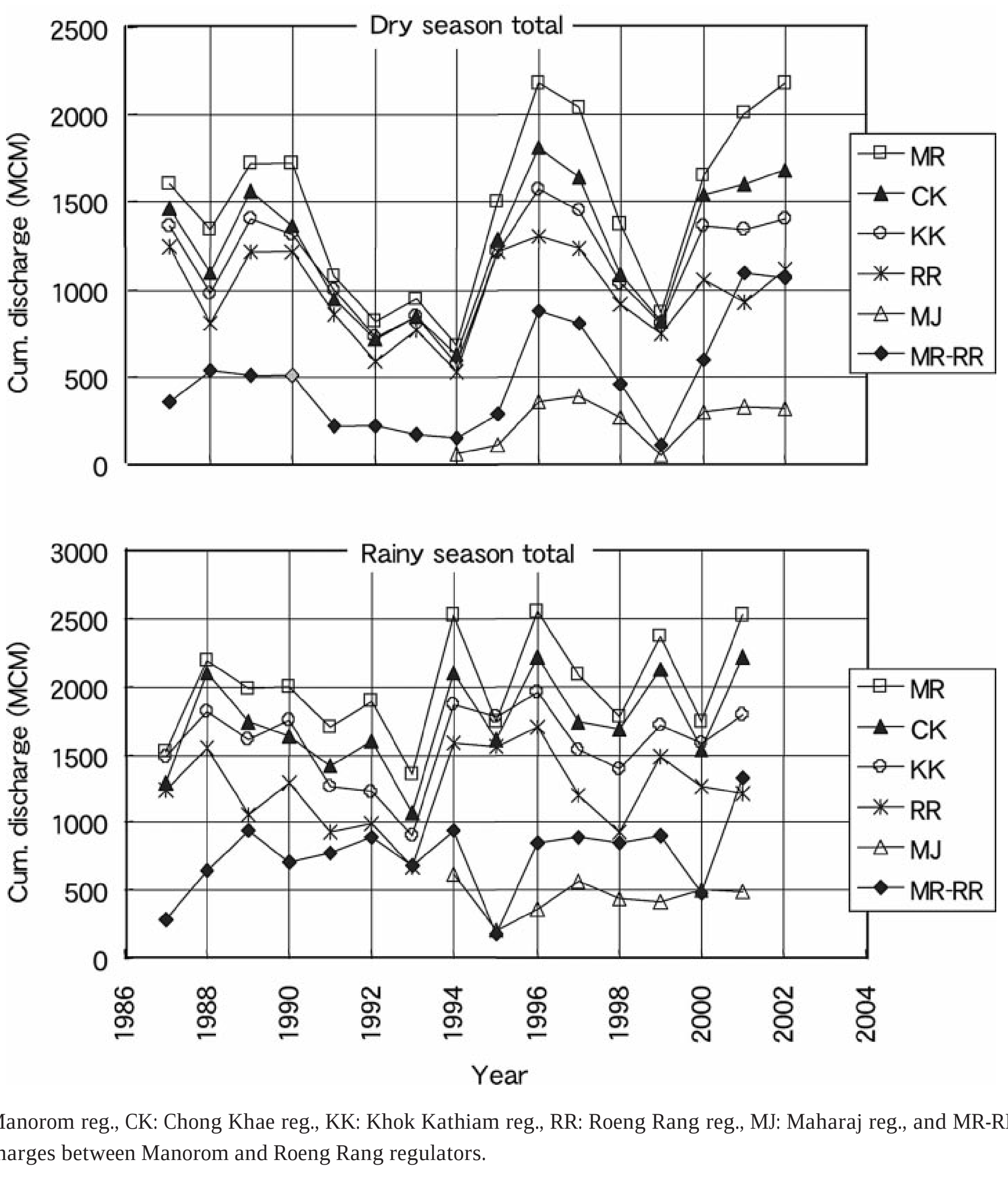


Fig. 4 Seasonal total inflow and release volumes of water at the Bhumibol and Sirikit dams

b Water allocation from the main canals

Fig. 5 shows the seasonal cumulative discharges at the main regulators in the UEB area. The dry season cumulative discharges indicate that the water availability was very low in 1991-1994 and 1999 (Fig. 5). As for the rainy-season cumulative discharges, it is notable that, in 1990, 1995 and 2000, the discharges at Khok Kathiam regulator surpassed those at Chong Khae regulator (Fig. 5). This indicates that a significant amount of side-flows entered from the left-bank area into the Chainat-Pasak canal through spillways etc. between those two regulators.



Note: MR: Manorom reg., CK: Chong Khae reg., KK: Khok Kathiam reg., RR: Roeng Rang reg., MJ: Maharaj reg., and MR-RR: difference in discharges between Manorom and Roeng Rang regulators.

Fig. 5 Seasonal cumulative discharges at the main regulators in the UEB area (Above: dry season; below: rainy season)

4 Trends in cultivation

The variation in the cultivation areas in the dry seasons is shown in Fig. 6. Fig. 6 clearly shows that the rice cultivation areas fluctuated greatly in accordance with the water availability during the dry season. It is notable that, in draught years in 1991 to 1994 and 1999, the rice cultivation area decreased significantly while the crop/vegetable category increased its cultivation area. On the other hand, in other years, most of the cultivation areas were occupied by rice and the contributions by other crops were negligible. Meanwhile cultivation areas of the rainy-season rice shows a

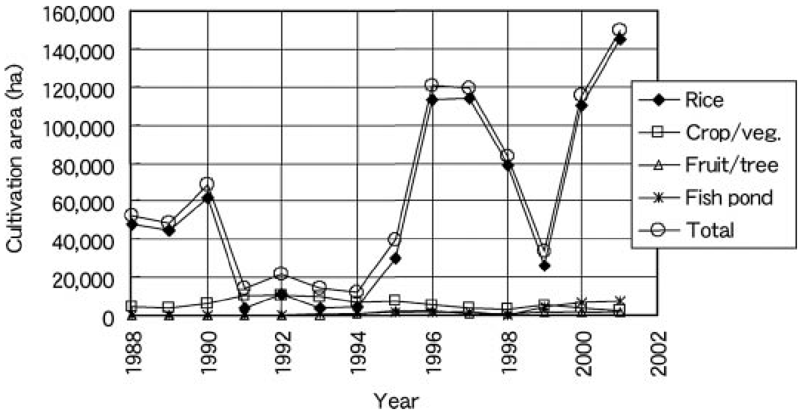


Fig. 6 Trends in cultivation areas of dry-season crops within the UEB area

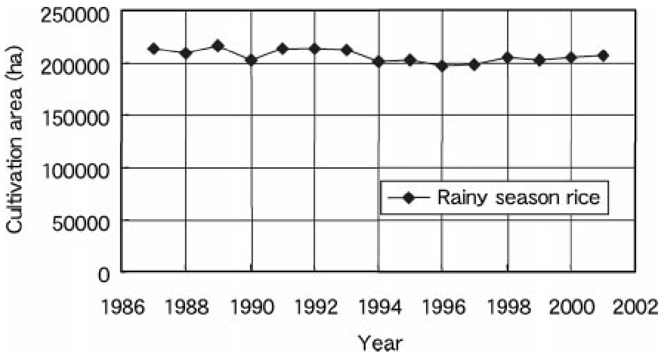


Fig. 7 Trends in cultivation areas of rainy-season rice within the UEB area

relatively stable trend compared to the dry-season rice (Fig. 7).

The above trends can largely be attributed to the rainfall conditions in the UEB area (Fig. 8). The UEB area received 377 mm of rainfall in the dry season and 801 mm in the rainy season on average between 1942 and 1988. On the other hand, the total water demand of rice was generally estimated as 1250 mm/season (=2000 m3/rai/season) as mentioned earlier. Comparing the above rainfall and water demand, it is clear that the rainy-season rice was less dependent on water availability from the irrigation canals than the dry-season rice.

Comparison between the target and actual cultivation areas of the dry-season rice (Fig. 9) indicates a general trend that the actual cultivation areas have steadily increased over the period excluding the draught years. Moreover, the gap between the target and actual areas were widening as the ratios between them have stayed above 170% since 1998 (Fig. 9). This has led to increasingly serious competitions for irrigation water in the UEB area in recent years.

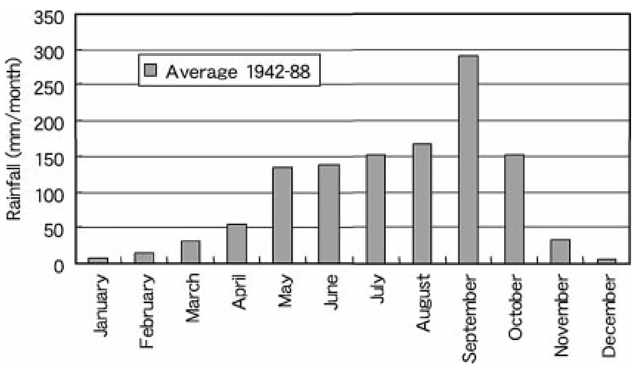


Fig. 8 Average monthly rainfall in the UEB area between 1942 and 1988

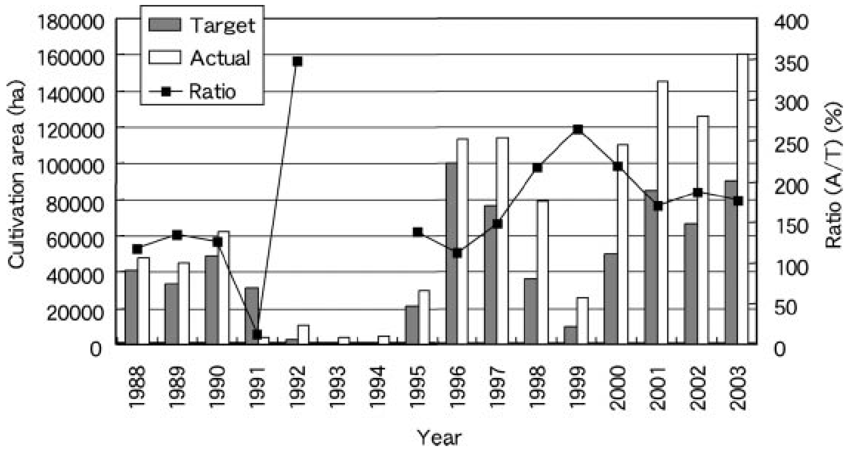


Fig. 9 Target and actual dry-season rice cultivation area within the UEB area

Fig. 10 shows the trends in cultivation areas in 4 Project areas along the Chainat-Pasak canal from 1987 to 2001. During that period, the area suffered from water shortage in the dry seasons between 1991 and 1994, and again in 1999. In those draught years, the upstream Projects, particularly Manorom Project, managed to cultivate some paddy fields while the downstream Projects had to reduce rice cultivation to almost none (Fig. 10). It is considered that, in such draught situations, the farmers in Manorom Project supplemented or substituted canal water by groundwater from the shallow wells to cultivate a little area of paddy fields, as shown in the following section.

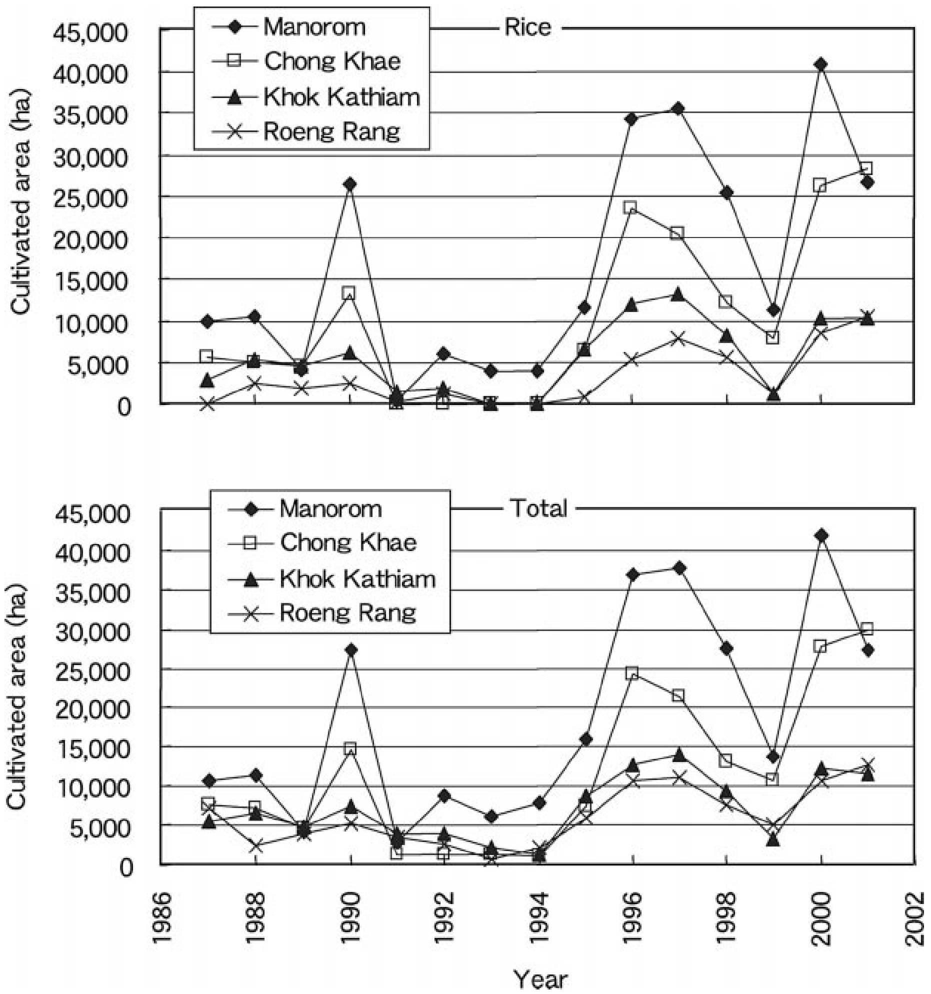


Fig. 10 Trends in cultivation areas in 4 Projects along the Chainat-Pasak canal during the dry season (Above: paddy rice only; below: total of all crops)

5 Use of groundwater for supplementing canal water

According to the questionnaire survey, shallow wells were largely concentrated in Manorom Project and the upper part of Maharaj Project (Fig. 11). Farmers were supposed to use those shallow wells for supplementing irrigation water when the water supply from canals was suspended or not enough for cultivation. (Most of the shallow wells are owned by farmers themselves, and they are free to use any available groundwater, as groundwater use is currently not regulated in Thailand excluding the Bangkok metropolitan area.) Such a sort of water use has been known as "conjunctive use of surface and ground water", and reported in the West Bank of the Chao Phraya Delta (Chulalongkorn University, 2002) as well as in the Ganges River basin in northern India (Ueda and Kaida, 1994), where extensive canal systems supply irrigation water. Such extensive canal systems may sometimes fail to supply irrigation water in a timely manner, but could recharge groundwater through seepage losses. For these reasons, farmers in those regions are considered to supplement surface water by installing private shallow wells, in order to achieve timely irrigation.

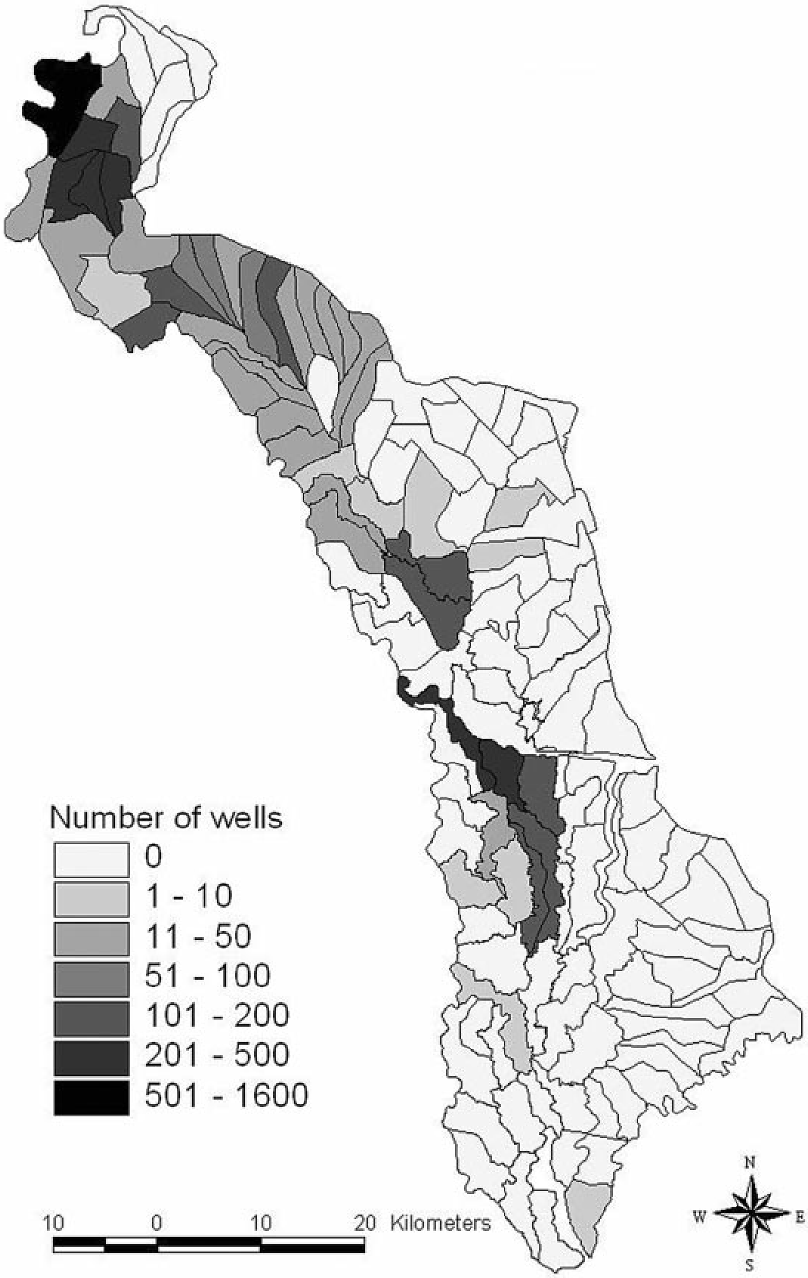


Fig. 11 Distribution of shallow wells in the UEB area

6 Relationship between water allocation and cultivation

Figs. 12 and 13 show the relationships between the seasonal cumulative discharges and the rice equivalent areas for the C-P and C-A areas. As for the dry season, both the C-P and C-A areas showed good correlations between these two factors (Fig. 12). Fig. 12 also showed interesting gaps between the origin and x-intercepts of the regression lines. These gaps might imply conveyance and other losses within the canal systems, which would not be used for cultivation. As for the rainy season, the correlations were negligible (Fig. 13), because in rainy seasons the rice cultivation areas tended to expand to the maximum potential regardless of water availability from the canals.

Water duties in the dry seasons were calculated for the two areas using the following equation:

$$D_W = Q_{cum} / A_{RE} \quad (4)$$

Where: D_W is a water duty;
Q_{cum} is a seasonal cumulative discharge to the area; and
A_{RE} is a rice equivalent area.

For determining a representative water duty, the authors selected and averaged the water duties between 1995 and 2001 (Table 2), in order to exclude data before 1994, which showed variable results, possibly because of some inaccuracy in the cultivation data in draught years.

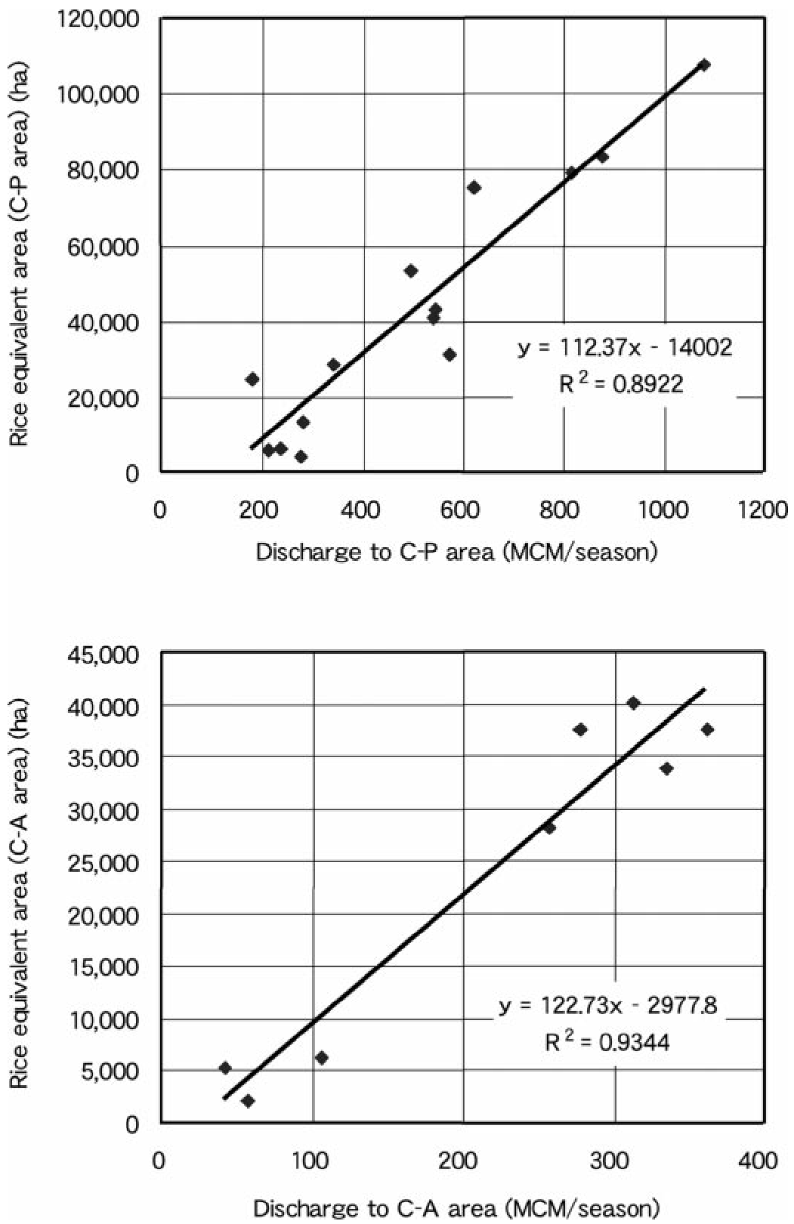


Fig. 12 Relationships between discharges and cultivation areas in the dry season

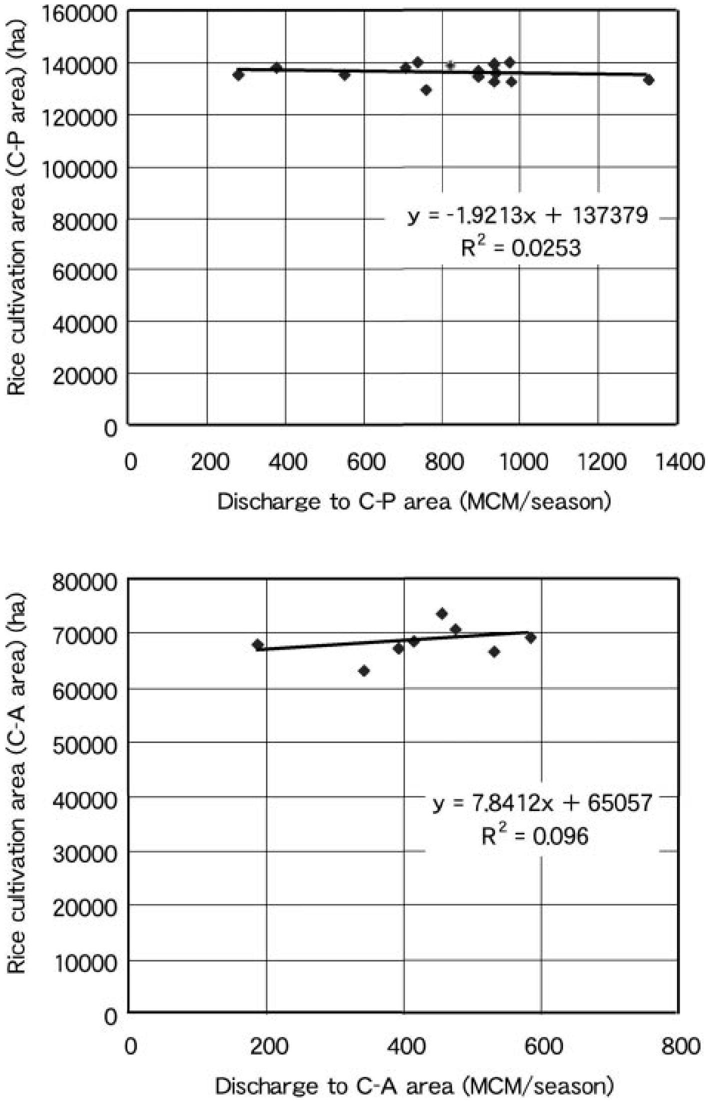


Fig. 13 Relationships between discharges and cultivation areas in the rainy season

Table 2 Average water duties in the dry seasons during 1995-2001

	(m^3/rai/season)	(m^3/ha/season)	(mm/season)
C-P area	1544	9648	965
C-A area	1581	9881	988

7 Summary

This section identified some trends in cultivation and water allocation in the UEB area since 1987 as follows:

- In dry seasons, cultivation of field crops and vegetables tended to increase in draught years, while in normal years farmers tried to expand rice cultivation as much as possible in accordance with the water availability from the canals.
- In rainy seasons, cultivation of rice paddy tended to expand to the maximum potential regardless of water availability from the canals.
- A general trend was observed that the actual cultivation areas of dry-season rice have increased over the period excluding the draught years. Moreover, the gap between the target and actual areas were widening in recent years.
- In severe draught years, the upstream Projects were able to cultivate a little area of paddy fields. The farmers in those Projects were supposed to supplement or substitute canal water by groundwater taken from private shallow wells.

- A good correlation was observed between the cultivation area and the total water allocation in the dry season.
- The water duties for the dry-season crops were estimated as 965 and 988 (mm) for the C-P and C-A areas, respectively.

III Simultaneous discharge measurements

1 Introduction

The Basin and Delta Level Water Management Working Group has conducted simultaneous discharge measurements four times in 2002 and 2003 in the Upper East Bank (UEB) of the Chao Phraya Delta. The objective of this activity is to measure discharge simultaneously at main points where water flows into or out of hydrological blocks within the UEB area. No attempt like these measurements has been made previously in this area. Thus, the results would make it possible to understand the actual water balance of the UEB area at a certain time.

2 Materials and methods

The simultaneous discharge measurements were conducted four times on 10-12 September 2002, 20-21 November 2002, 11 March 2003, and 20-21 May 2003. Ideally speaking, all the measurements should be conducted exactly at the same time (simultaneously), but in practice the measurements were conducted within 2 or 3 days by 4 to 6 teams, all of which belonged to Hydrology Center 5 in Chainat and equipped with a current meter. Discharges were measured at the nearest bridges upstream of the designated regulators or points. The discharge data at Chao Phraya dam, Nakhon Sawan, and Rama VI regulator were obtained at the RID Head Office.

For calculating the water balance, the UEB area was divided into two hydrological blocks. The dividing line between the two blocks was the Lopburi River (between the upper river mouth at Singburi and Wat Manee regulator) (see Figs. 14 to 17). Although some scattered rains were observed during the November-2002 measurements, the contributions from rainfall within the UEB area and sideflows from outside the UEB area were neglected for simplicity.

3 Results and discussion

The results of the discharge measurements are summarized in flowcharts (Figs. 14 to 17) and water balances (Table 3).

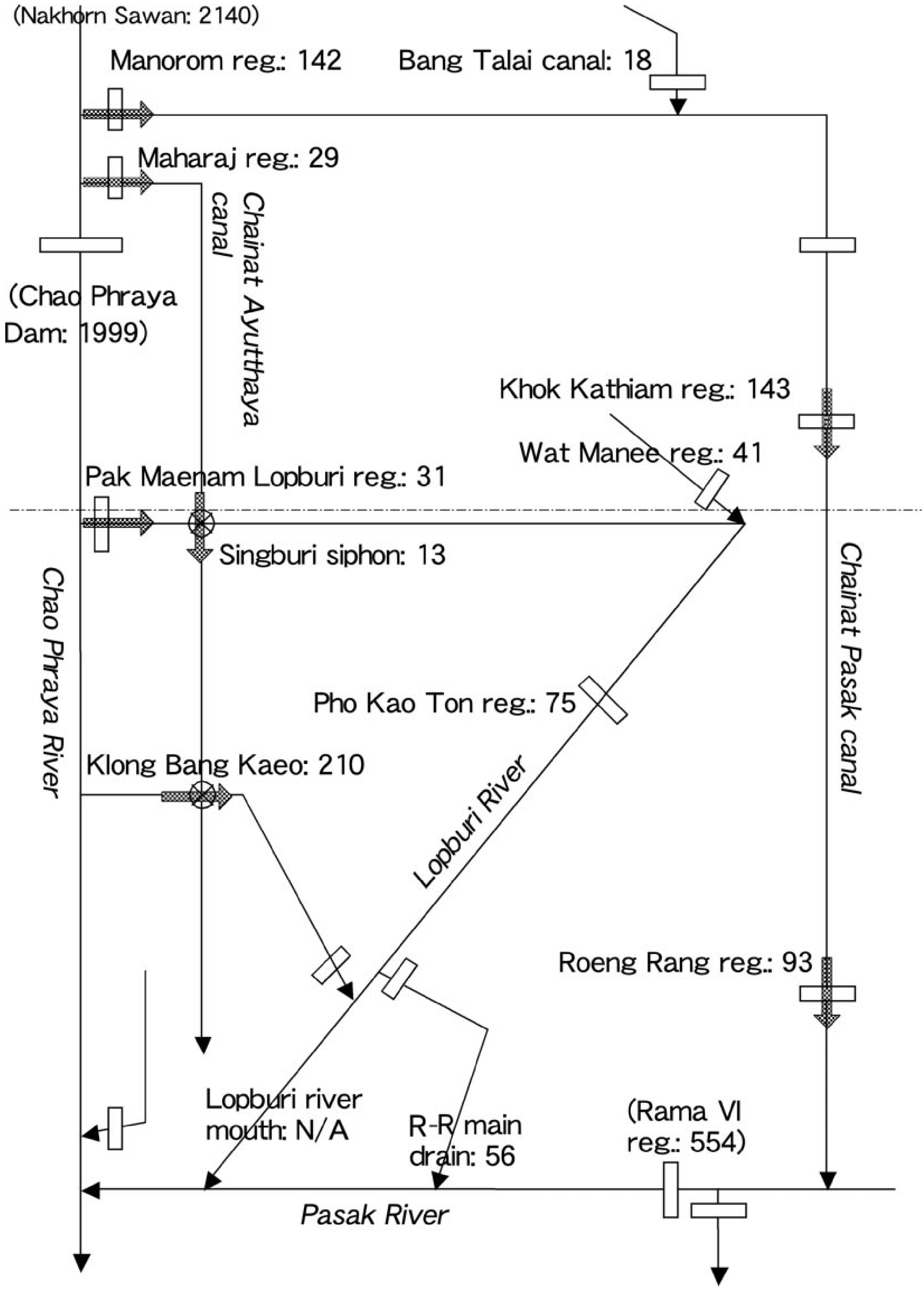
The results in September 2002 (Fig. 14) indicate that the inflows from the Chao Phraya River to the UEB area were thought to exceed the outflows from the UEB area into the Lopburi and Pasak Rivers. At that time, the water levels in the Chao Phraya and Pasak Rivers were very high due to the heavy flood in the upstream of these rivers. Accordingly, due to the backwater effect from these rivers, the discharges at the mouths of Roeng Rang main drain were relatively small (Fig. 14). Similarly one could expect a relatively small discharge at the mouth of Lopburi River, at which the data was missing (Fig. 14). Thus, one could guess that most of the excess water flowing into the UEB area was spreading into the fields within the lower block of UEB area, as indicated in Table 3.

The results in November 2002 (Fig. 15) show that the inflows from the Chao Phraya River to the UEB area were still high. At the same time, however, considerable amount of water was flowing out of the UEB area thanks to the decreasing water levels in the Chao Phraya and Pasak Rivers. Consequently the water balance showed minus figures for the total UEB area and for the lower block (Table 3).

The results in March and May 2003 (Figs. 16 and 17) indicate that outflow from the UEB area is confined to that at Roeng Rang regulator, while those at the Lopburi River and drainage canals were zero. This means that virtually all the water diverted to the lateral canals along the Chainat-Pasak and Chainat-Ayutthaya canals was consumed within the UEB area. In fact, it is known that farmers tend to reuse water flowing from upstream areas down to drainage canals, by using mobile pumps etc.

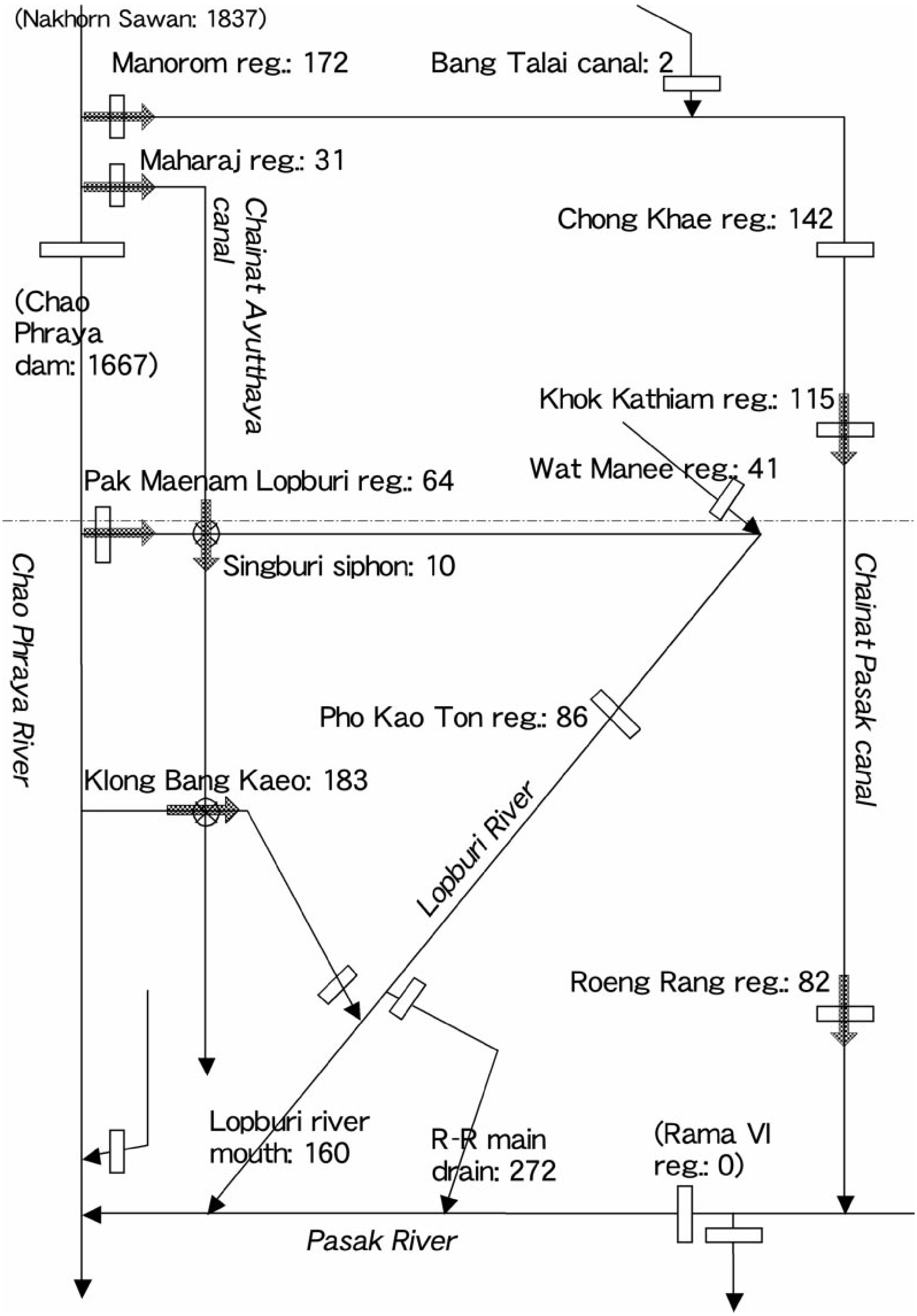
4 Summary

The results are summarized as follows: (1) in the beginning of the rainy season, the inflow exceeded the outflow, and the excess inflow was spreading into the lowlands; (2) toward the end of the rainy season, the outflow exceeded the inflow, and the inundation was receding; (3) in the dry season, virtually all the irrigation water was reused within the UEB area.



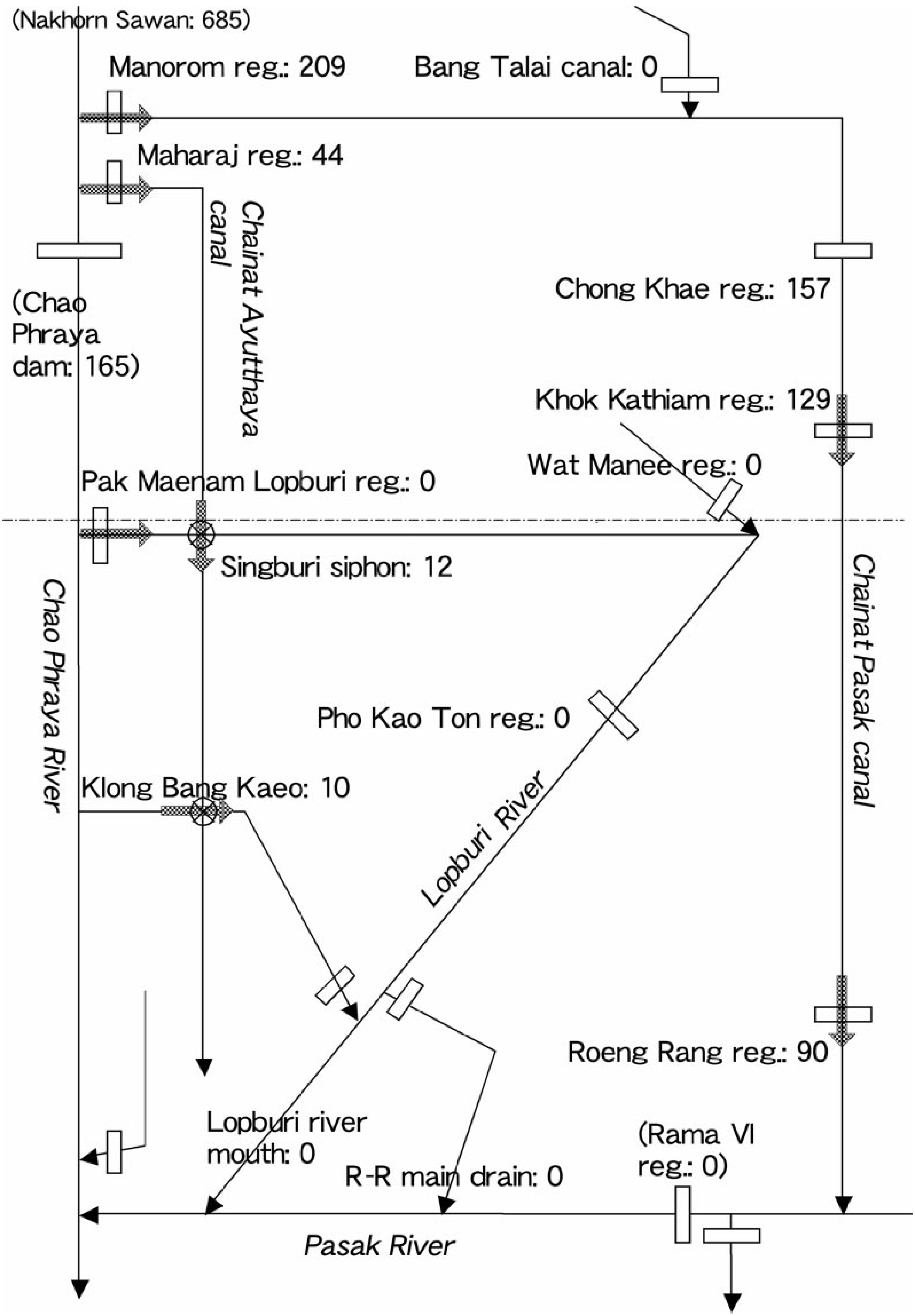
Note: The broken line indicates the borderline between the upper and lower blocks. The discharge datum was missing at the mouth of Lopburi River. Unit: m^3/s.

Fig. 14 Summary flowchart of simultaneous discharge measurement on 10-12 September 2002



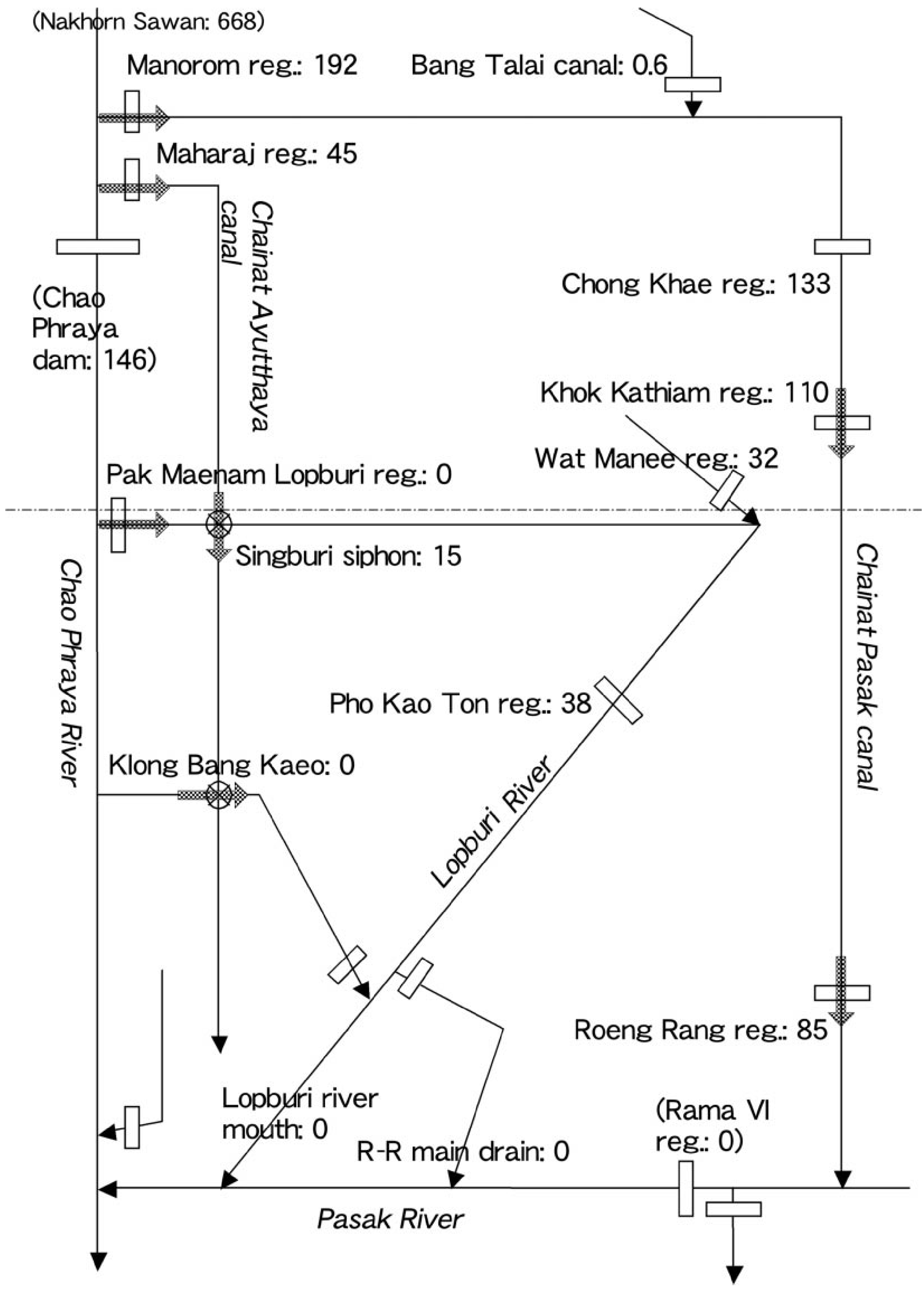
Note: The broken line indicates the borderline between the upper and lower blocks. Unit: m^3/s.

Fig. 15 Summary flowchart of simultaneous discharge measurement on 20-21 November 2002



Note: The broken line indicates the borderline between the upper and lower blocks. Unit: m^3/s.

Fig. 16 Summary flowchart of simultaneous discharge measurement on 11 March 2003



Note: The broken line indicates the borderline between the upper and lower blocks. Unit: m^3/s.

Fig. 17 Summary flowchart of simultaneous discharge measurement on 20-21 May 2003

Table 3 Water balance of the Upper East Bank of the Chao Phraya Delta

Unit : m^3/s

Date		UEB total	Upper block	Lower block
10-12 September 2002	Inflow	430	189	438
	Outflow	149+*x**	197	149+*x**
	(In)-(Out)	281-*x**	Minus 8	289-*x**
20-21 November 2002	Inflow	452	205	413
	Outflow	514	166	514
	(In)-(Out)	Minus 62	39	Minus 101
11 March 2003	Inflow	263	253	151
	Outflow	90	141	90
	(In)-(Out)	173	112	61
20-21 May 2003	Inflow	238	238	157
	Outflow	85	157	85
	(In)-(Out)	153	81	72

Note: The dividing line between the upper and lower blocks is indicated in Figs. 14 to 17.
The above inflows and outflows were calculated by summing up the following items (see Figs. 14 to 17):

UEB total: Inflow: Manorom reg., Maharaj reg., Bang Talai canal, Pak Maenam Lopburi reg. and Klong Bang Kaeo.
Outflow: Roeng Rang reg., Lopburi river mouth and R-R main drain.

Upper block: Inflow: Manorom reg., Maharaj reg. and Bang Talai canal.
Outflow: Singburi siphon, Wat Manee reg. and Khok Kathiam reg.

Lower block: Inflow: Pak Maenam Lopburi reg., Singburi siphon, Wat Manee reg. and Khok Kathiam reg. and Klong Bang Kaeo.
Outflow: Roeng Rang reg., Lopburi river mouth and R-R main drain.

*In September 2002, the discharge datum was missing at the mouth of the Lopburi River, which was indicated by the letter *x*.

IV Remote sensing analysis

1 Introduction

From 1999 to 2001, the Basin and Delta Level Water Management Working Group has been engaged in GIS-related activities, and established some GIS layers of the UEB area, including administrative boundaries, networks of water management facilities and hydrology stations.

Following these activities, in 2002, the Working Group started the activities on remote sensing analysis. Using the remote sensing technologies, we estimated (1) cultivation conditions in the UEB area (November 2002), and (2) inundation conditions in the Chao Phraya River Basin (September 2003). This section summarizes the outcomes of these activities.

2 Materials and methods

We employed ERDAS IMAGINE Professional 8.5 for analyzing satellite images and ESRI ArcGIS 8 for creating and manipulating GIS layers.

a Estimation of cultivation conditions in the UEB area

For the estimation of cultivation conditions in the UEB area, we employed two satellite images, namely LANDSAT/ETM+ data No.129-50 (16th November 1999) and LANDSAT/TM data (25th December 1993). An outline of the procedures of the analysis is shown in Fig. 18. These raw satellite images were first geo-corrected, and then the land covers were classified into 40 classes using the unsupervised classification techniques (ISODATA method).

The above 40 classes were re-classified manually by consulting reference materials (Molle et al., 1999; 2001), interviews with Project Offices and field surveys. Firstly the LANDSAT/TM data were used to distinguish paddy fields from other land uses, such as urban area, road, forest, and water bodies. Secondly, by employing the LANDSAT/ETM+ data, the authors aimed to further classify the cultivation conditions of paddy fields in the UEB area as of 16th November 1999. Consequently we classified the paddy fields into 5 categories, namely land preparation/planting, harvested, near harvest, growing (shallow water), and growing (deep water/floating rice).

The deep-water rice fields could be identified by the difference in land-surface reflections. Such a distinction was possible because, in such fields, the silt and clay in water had been settled down and the land surface was sparsely covered by rice. Accordingly such fields appeared dark in satellite images. On the other hand, it was rather difficult to distinguish paddy fields from orange farms due to the similarity in land-surface reflections. Although there are relatively small areas of orange farms compared to paddy fields at present, more field surveys might be necessary to distinguish them in the future.

The above two re-classified data (LANDSAT/TM and LANDSAT/ETM+) were overlaid onto each other, and an area of the Upper East Bank (UEB) was cut out to obtain the final land classification map.

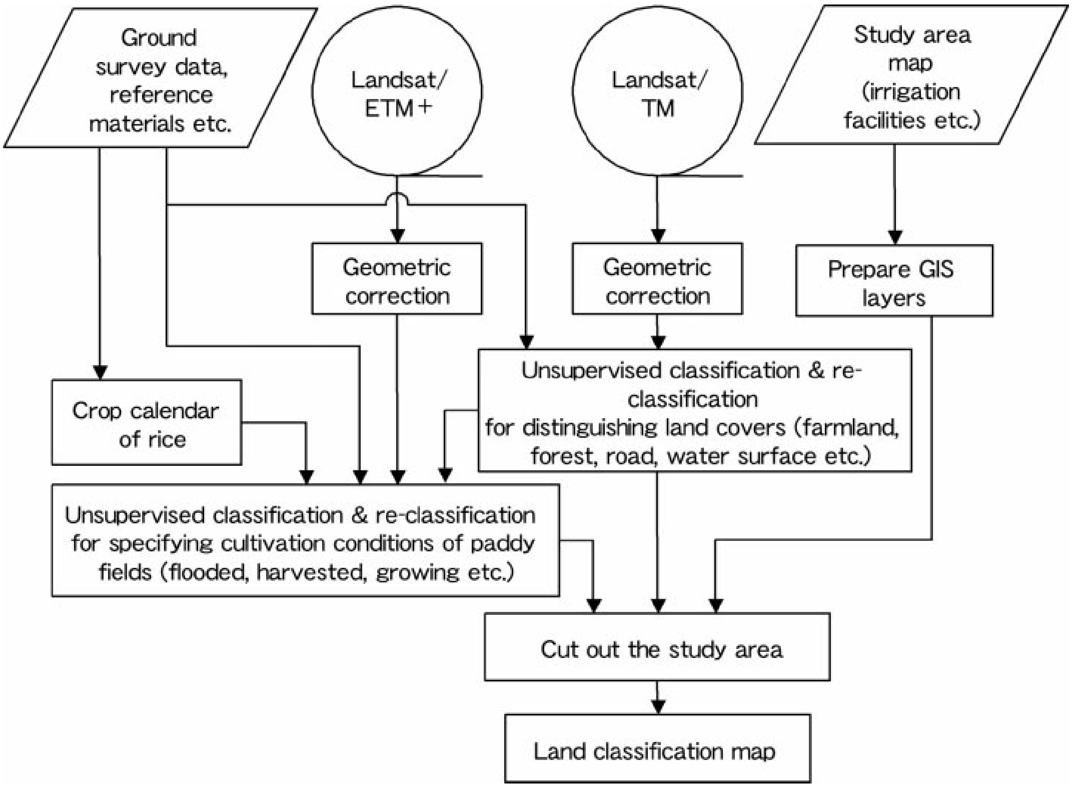


Fig. 18 Outline of the remote sensing analysis for the LANDSAT data

b Estimation of inundation conditions in the Chao Phraya River Basin

For the estimation of inundation conditions in the Chao Phraya River Basin, we employed three sequential MODIS data (9th October, 10th November, and 12th December 2002). Since MODIS image has a wide area of observation, we set the study area on the whole Chao Phraya River Basin.

Procedures for the analysis are shown in Fig. 19. Images of the study area were cut out from the raw satellite data mentioned above, and then geo-corrected. Next the inundated areas were identified using the supervised classification techniques. Finally we overlaid the three sequential images of MODIS to trace the change in inundation conditions in the river basin.

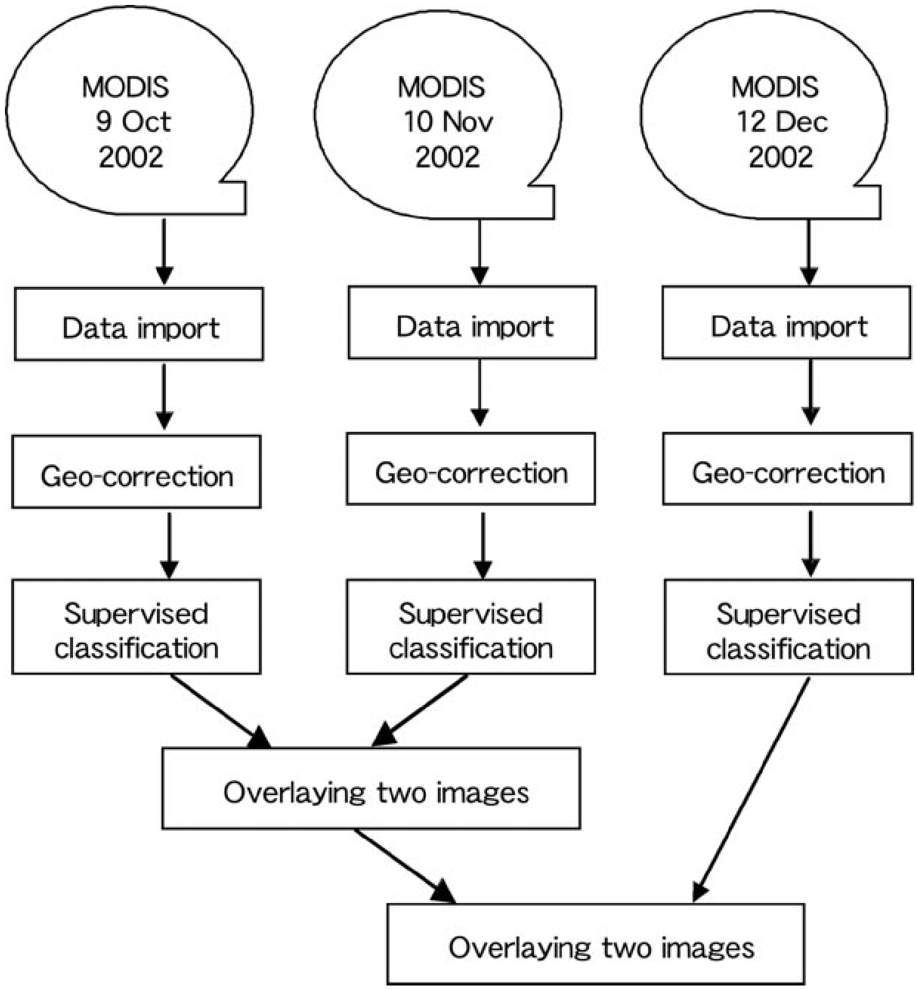


Fig. 19 Outline of the remote sensing analysis for the MODIS data

3 Results and discussion

a Estimation of cultivation conditions in the UEB area

The remote-sensing analysis using the LANDSAT data revealed the difference in cropping patterns within the UEB area (Fig. 20). Manorom Project, the upper part of Maharaj Project, and some areas along the Chainat-Pasak canal apparently contain a number of paddy fields at near-harvest, post-harvest or land preparation stages, indicating a cropping calendar of rice starting from November. By contrast, rice crops were largely under the growing stage in other areas. According to our interviews with Project Offices, a cropping calendar of paddy rice starting from November was associated with quite intensive or almost continuous rice cultivation, namely 3 times a year or 5 times in 2 years (Fig. 21). Therefore the results suggested that more farmers in the above-mentioned three regions performed intensive rice cultivation than those in other areas.

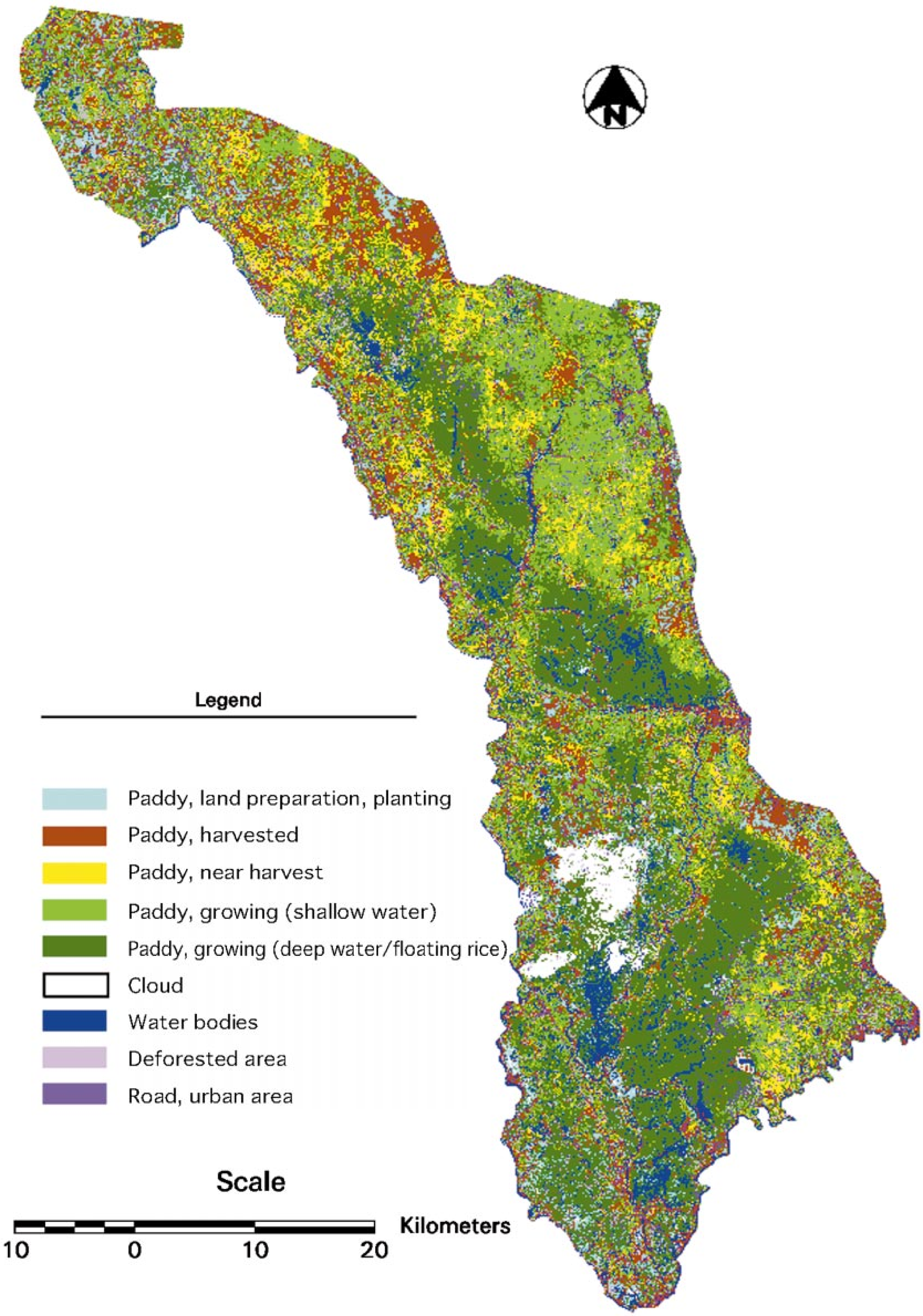


Fig. 20 Land classification map on 16 November 1999 in the study area
Note: The uppermost part of the study area was excluded because the satellite image was unavailable.

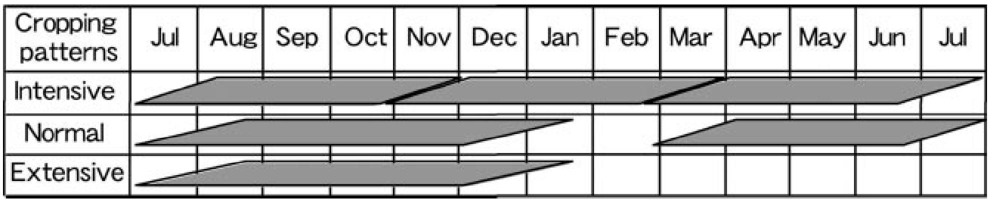
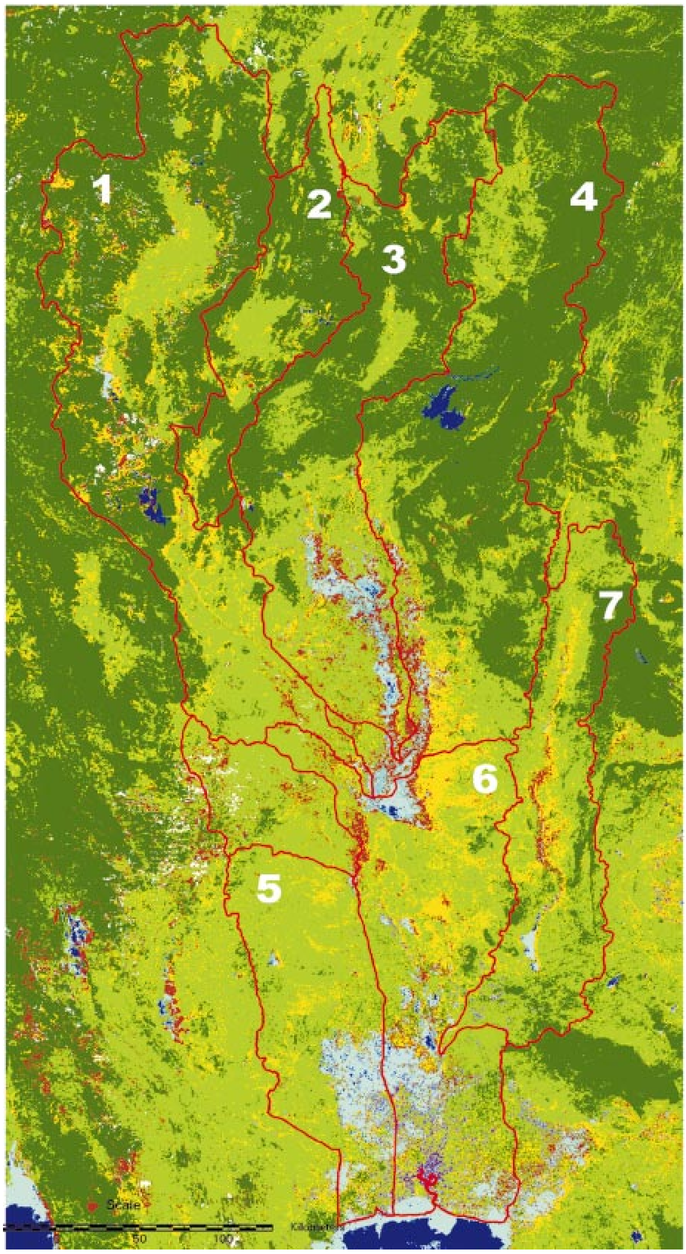


Fig. 21 Typical cropping patterns of rice in the study area
High Yield Varieties of rice normally take about 120 days for cultivation while Traditional Varieties about 150-180 days.

b Estimation of inundation conditions in the Chao Phraya River Basin

In the rainy season 2002, heavy floods occurred in many areas across the Chao Phraya River Basin. The remote sensing analysis with the MODIS data (Fig. 22) revealed that the following areas suffered from an extended period of inundation: (1) the middle river basin, especially the catchment areas of the Nan and Yom Rivers; and (2) middle to lower parts of the Chao Phraya Delta.



Legend

	9 Oct.	10 Nov.	12 Dec.
Light blue	I	I	I
Brown	I	I	V
Yellow	I	V	V
Light green	V	V	V

I=inundated; V=covered with vegetation

Dark green: Forest
White: Cloud
Dark blue: Water body

Red lines: Watersheds of tributaries (see also Fig. 1)
1. Ping River; 2. Wang River; 3. Yom River; 4. Nan River; 5. Tha Chin River; 6. Chao Phraya River; 7. Pasak River.

Fig. 22 Inundation condition in the Chao Phraya River Basin in the rainy season 2002

V Methods for water management planning in the dry season

1 Introduction

This section describes the methods for making the dry-season water allocation plan in the UEB of the Chao Phraya Delta, which are generally adopted by the RIO-10 and Project Offices at present. The necessary information was mainly drawn from the interviews with RID officials at the above offices in 2002, as those offices had no stipulated guidelines for water management planning at that time.

Before the dry season irrigation starts every year, a seasonal water allocation plan from January to June is prepared in order to match the cultivation areas, especially those of rice, with the available amount of water from major reservoir dams. Such a pre-seasonal plan is not prepared for the rainy season (July to December) at present. (Some attempts have been made, though, to prepare such a plan for the rainy season in a few previous years, but the plans were not used in practice.) Therefore the following statements are solely concerned with the dry-season irrigation planning. An outline of the decision-making process is shown in Fig. 23.

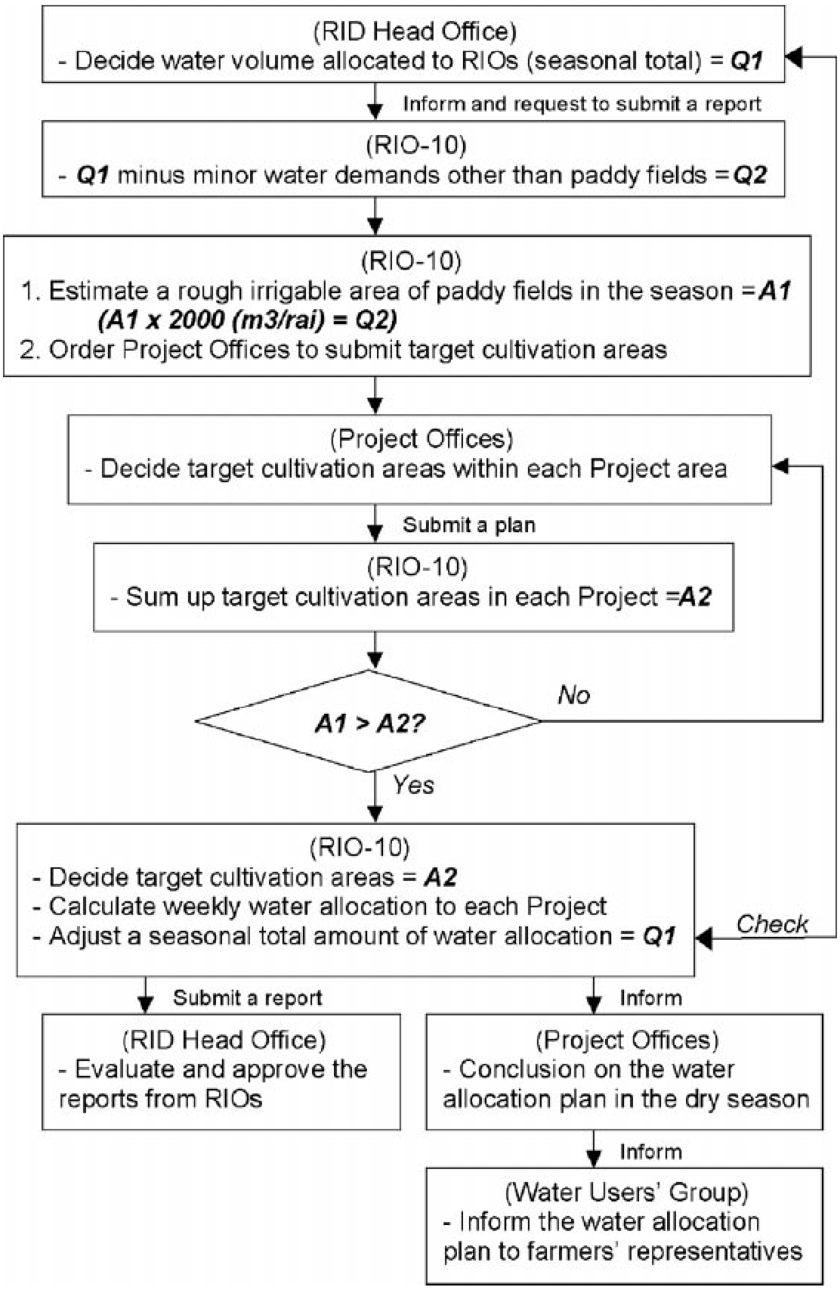


Fig. 23 Outline of the decision-making process for the dry season irrigation planning

2 Water allocation plan for the Chao Phraya River basin

In November, RID, Department of Agriculture Extension, Electricity Generating Authority of Thailand (EGAT) and other relevant authorities hold a working committee to decide the water allocation plan from January to June for each region and sector. The decision is made on the basis of forecasted active storage in Bhumibol and Sirikit dams on 1st January, which has been classified in criteria (Table 4) in accordance with the analysis on water situations between 1975 and 2003 (MWMS Project, 2003).

Table 4 Criteria of water allocation from Bhumibol and Sirikit dams in the dry season

Unit: MCM

		Very few year	Few year	Normal year	Plenty year
Active Storage on 1st January at Bhumibol and Sirikit dams		Lower than 4,000	4,000 to 6,500	6,500 to 12,000	Higher than 12,000
Water demands	1. Water uses upstream of Nakorn Sawan	300	500	1,300	1,300
	2. Water use in the Greater Chao Phraya Project	900	2,100	3,300	5,500
	3. Navigation	0	200	300	300
	4. Metropolitan Waterworks Authority	550	650	750	750
	5. Salinity Control	250	350	350	350
Total release from Bhumibol & Sirikit dams		2000	3800	6000	8500
Release from the Pasak dam		500	500	500	500
Dry season paddy field in the Phitsanulok and the Greater Chao Phraya Projects (in million rai)		1.00	1.50	3.10	4.10

Note: 1 rai=0.16 ha

If the water storage in the upstream dams is enough to support every water-use activity in the river basin, the water allocation from Bhumibol and Sirikit reservoir dams does not emphasize on priority consideration. If water crisis happens, however, the water allocation will be decided considering the priorities of water usage among sectors both in the river basin and within the agricultural sector as well. The following priority order of water usages is normally followed by the concerning authorities (MWMS Project, 2003):

(Priority)
Number 1 Water supply in the river basin, including domestic consumption and the industries
Number 2 Agriculture that uses less water
Number 3 Salinity control at the Chao Phraya and the Tha Chin River mouths
Number 4 Dry season rice cultivation
Number 5 Water transportation

Water allocation for agriculture is considered according to the following priorities:
Number 1 Fish ponds and other fisheries
Number 2 Vegetables and orchards
Number 3 Field crop cultivation
Number 4 Dry season paddy cultivation

Accordingly RID Head Office decides the seasonal total amount of water that is allocated to each Regional Irrigation Office (RIO) area. After the above decision is made, RID Head Office informs the total amount of water available in the coming dry season within the RIO-10 area, and asks the RIO-10 to make the water allocation plan throughout the dry season.

Total amount of water available for RIO-10 = Q_1 (MCM/season) (5)

3 Rough estimation of an irrigable area of rice paddy fields within the RIO-10 area

The RIO-10 estimated a total irrigable area of rice paddy fields as follows. For the calculation of irrigable area,

Table 5 Standard water requirement for dry-season crops

Units	m^3/rai/season	m^3/ha/season	mm/season
Rice paddy	2,000	12,500	1,250
Field crop/vegetable	1,000	6,250	625
Fruit/perennial tree	1,400	8,750	875
Fishpond	1,000	6,250	625

Note: 1 rai=0.16 ha

the RIO-10 uses the following "standard" values of unit water requirement (or water duty) for each crop, which include both the water demands for consumptive use and land preparation (Table 5). These standard values derive from past experiences.

Since cultivation areas of fruit/perennial trees and fishponds, which are located mostly in the Lower East Bank, do not change over years very much, their cultivation areas are held as constants. As of 2002, cultivation areas of fruit/perennial trees and fishponds are tentatively assumed as 200,000 rai (equivalent to 280 MCM/season) and 90,000 rai (equivalent to 90 MCM/season), respectively. These figures may be corrected in the future for matching to actual situations. Thus the water requirements for fruit trees and fishponds are subtracted from the total available water Q_1 as follows:

$$Q_1 \text{ (MCM)} - 280 \text{ (MCM)} - 90 \text{ (MCM)} = Q_2 \text{ (MCM)} \qquad (6)$$

The above figure Q_2 is used as a tentative estimation of available water for dry-season rice paddy fields. Using the standard water requirement (Table 5), the irrigable area of rice paddy field in RIO-10 is then estimated as follows:

$$Q_2 \text{ (MCM/season)} \times 10^6 / 2{,}000 \text{ (m}^3\text{/rai/season)} = A_1 \text{ (rai)} \qquad (7)$$

At this step of rough estimation, water requirement for vegetable and field crops is neglected because such fields within the RIO-10 area would require only negligible amount of water as a whole.

4 Determination of irrigable areas of rice paddy fields

The RIO-10 requests the Project Offices to make a detailed plan of rice cultivation in the coming dry season.

Accordingly each Project Office makes a plan of rice paddy field cultivation. The plan shows the locations (district and sub-district) and areas of paddy fields within the command of each lateral canal.

The RIO-10 collects the above plans from the Project Offices, and sums up the areas of rice paddy field cultivation.

$$\text{Total rice cultivation area requested by Project Offices} = A_2 \text{ (rai)} \qquad (8)$$

If the above area A_2 is less than the irrigable area A_1, the RIO-10 proceeds to the next step. If the area A_2 is more than the area A_1, the RIO-10 then asks some Project Offices to reduce rice cultivation areas within their Projects until the area A_2 gets smaller than the area A_1. For example, the RIO-10 may ask Project Offices to remove some fields that are located at the end of lateral canals from their plan, because irrigation water may not reach there in the coming dry season.

After the above adjustments are made, the final target cultivation areas in the RIO-10 are determined at the Project and lateral-canal levels.

5 Making the weekly water allocation plan at the Project level

According to the target cultivation areas that have been determined, the RIO-10 allocates irrigation water to each Project area. At this step the RIO-10 also allocates water to some sectors other than agriculture, such as water works companies (domestic water supply), the military and hospitals. These sectors also take water from irrigation canals, but occupy relatively small shares in water use when compared to the agricultural sector. For example, according to the plan for the dry season 2002, around 94% of water from Chainat-Pasak Canal is to be allocated to the agricultural sector.

Then the RIO-10 decides weekly water allocation to the main canals in the RIO-10 and some minor canals that take water directly from the Chao Phraya River. The water demand for agriculture is calculated using the method and data of the Chao Phraya and Meklong Basin Study, Phase 2 (ACRES International Ltd., 1980), which is described below in details. Finally the RIO-10 should adjust the seasonal total of the allocated water equal to the plan of RID Head Office. Thus,

(Seasonal total amount of water to be diverted to the canals in the Upper and Lower East Bank of the Chao Phraya Delta)

= Q_1 (MCM/season) (the allocated release discharge from Bhumipol, Sirikit and Pasak dams for this area) (9)

6 Confirmation of the overall water allocation plan

The RIO-10 compiles a report that contains the above water allocation plans, and sends it to the RID Head Office. The above procedures would normally take about 2 weeks. The RID Head Office then examines the report and, if no problem is found, approves the report. In the meantime the RIO-10 sends the same report to the Project Offices as well.

The Project Offices then hold a zone meeting in order to inform farmers about the target cultivation area and the weekly water allocation plan. In the meeting the farmers will be interested in prohibition of rice cultivation outside the target area and whether the water supply is at a normal level or not. Based on such information, farmers will be able to consider the risk for dry season paddy cultivation outside the target area. They are solely responsible for the risk of such cultivation.

7 Calculation of the weekly water allocation plan (the method of RIO-10)

The following procedures are currently adopted by RIO-10 for calculating the weekly water allocation plan to each Project area and lateral canal. The target cultivation areas allocated to each Project are regarded as a precondition for the following calculation of water demands of paddy fields. The calculation is conducted on the basis of the method and data of the Chao Phraya and Meklong Basin Study, Phase 2 (ACRES International Ltd., 1980), but is somewhat simplified to adapt to the availability of data. An outline of the calculation procedures is summarized in Fig. 24.

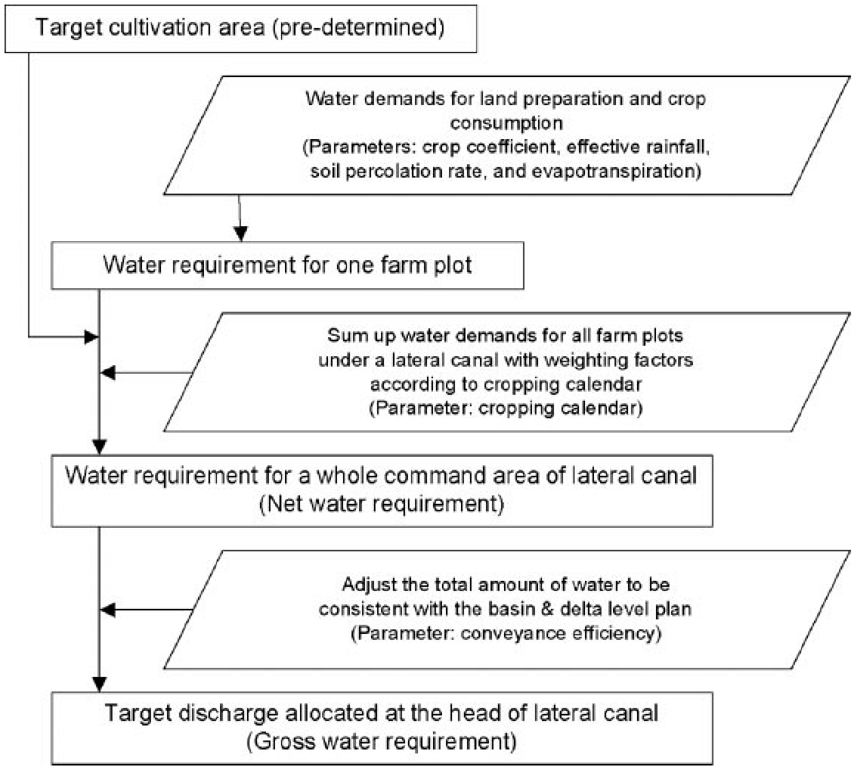


Fig. 24 Flowchart for calculating a weekly water allocation plan

In the RIO-10 area, each plot of farmland tends to start rice cultivation one after another (not simultaneously). Therefore it is important to set an appropriate assumption on crop calendars for calculation. Until 2002, the RIO-10 assumed that farmers start rice cultivation according to the "default" crop calendar (Table 6) provided by the ACRES model.

Nevertheless, the actual cropping calendars tend to change from year to year, depending on water situations.

Table 6 Crop calendars for rice cultivation

Week	1st	2nd	3rd	4th	5th	6th	7th	8th
Default area (%)	7	15	21	33	39	62	75	100
Revised area (%)	7	10	20	50	80	95	99	100

Note: The lower rows show a percentage of the cumulative cultivation area (i.e. a percentage of the area of paddy fields that have started rice cultivation by the corresponding week). The "Default area" derived from the default crop calendar provided by the ACRES model, while the "Revised area" from recent statistics in the UEB area.

Therefore the "default" crop calendar (Table 6) should be modified every year on the basis of field surveys. Thus, according to the discussion by the Basin and Delta Level Water Management Working Group, the RIO-10 adopted a revised cropping calendar for the dry season 2003 (Table 6) on the basis of recent statistics, trying to reflect actual situations in the UEB area.

Once a farmer starts rice cultivation, it is assumed that he grows rice with the "transplanting" method according to the schedule shown in Table 7.

Table 7 Standard schedule for rice cultivation

	Week	Water requirement*
1. Land preparation of a nursery bed	1st	150 mm/week
2. Raising rice crop in a nursery bed	2nd to 5th	Crop coefficient (= 1) x E_{tp}
3. Land preparation of a paddy field	4th to 5th	150 mm/2 weeks
4. Transplanting rice crop from a nursery bed to a paddy field	6th	-
5. Raising rice crop in a paddy field	From 6th	Crop coefficient x E_{tp}

Note: *Percolation loss of 1 (mm/day) is added to each item of water requirement.
*E*tp stands for evapotranspiration.

The irrigation requirements for land preparation (soaking and leveling of soils) of both a nursery bed and a paddy field are assumed to be 150 (mm) as a whole as follows:

$$R_{LPN} = 21 \text{ (mm/day)} = 150 \text{ (mm/week)} \quad (10)$$

$$R_{LPP} = 11 \text{ (mm/day)} = 150 \text{ (mm/2 weeks)} \quad (11)$$

Where: R_{LPN} is irrigation requirement for land preparation of a nursery bed; and
R_{LPP} is irrigation requirement for land preparation of a paddy field

Percolation loss of 1 (mm/day) is added to the above requirements.

During the nursery period of rice and after rice transplanting, the irrigation requirement is calculated as follows:

$$IR = E_{tp} + P_{erc} - R \quad (12)$$

$$E_{tp} = E_{tp0} \times C \quad (13)$$

Where: IR is irrigation requirement;
E_{tp} is evapotranspiration;
Perc is percolation, which is assumed constant at 1 (mm/day);
R is effective rainfall;
E_{tp0} is potential evapotranspiration (Table 8); and
C is crop coefficient

The crop coefficient C is assumed as 1.0 during the nursery period of rice, while after the rice transplanting, it is assumed according to Table 9. Effective rainfall R is neglected during the nursery period of rice, but, after the rice transplanting, it is assumed according to Tables 10 and 11.

The irrigation requirement calculated above is the water demand at each plot of farmland. The irrigation requirements at each plot are then summed up to calculate the irrigation requirement within the command of each lateral

Table 8 Potential evapotranspiration

Unit: mm/day

Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
4.9	5.9	6.3	6.5	5.5	5.2	4.7	4.4	4.5	4.5	4.9	4.6

Note: The above figures are potential evapotranspiration in Lopburi Province that are calculated according to the Penman method. These figures are assumed to represent the potential evapotranspiration in the Upper East Bank area.

Table 9　Crop coefficient for rice

Week	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th
	0.99	0.99	0.99	1.16	1.16	1.16	1.25	1.30	1.32	1.32	1.32	1.24	0

Note: The upper row shows the week since the transplanting of rice.
The crop coefficient during the nursery period of 4 weeks is held as constant (=1).
It is assumed that the water consumption by rice remains zero after the 13th week.

Table 10　Average rainfall between 1942 and 1988

Unit: mm/month

Project	Manorom	Chong Khae	Khok Kathiam	Roeng Rang	Maharaj
January	4.6	4.6	8.6	3.3	13.1
February	6.5	6.5	15.4	20.5	17.1
March	35.4	35.4	38.7	28.7	22.6
April	53.2	53.2	70.7	45.2	47.3
May	124.7	124.7	153.9	140.5	125.1
June	134.2	134.2	139.7	165.7	113.4
July	157.5	157.5	155.6	161.3	124.3
August	166.7	166.7	168.0	186.1	149.7
September	308.8	308.8	272.3	311.7	255.3
October	140.4	140.4	155.1	176.9	144.9
November	33.8	33.8	39.4	35.3	25.6
December	1.0	1.0	7.3	12.6	5.1

Note: The above figures are used for the calculation of effective rainfall.

Table 11　Conversion from total rainfall to effective rainfall

Unit: mm/month

Total rainfall	0	25	50	100	150	200	250	300	400	500
Effective rainfall (October)	0	25	50	92	95	100	100	100	100	100
Effective rainfall (Other months)	0	25	50	100	126	135	147	156	160	160

Note: Linear relationships are assumed between the above items.

canal (i.e. the net water requirement). In summing up the demands, the weighing factors are employed that reflect the assumed crop calendar (Table 6).

In order to calculate the amount of water to be supplied at the heads of lateral canals or main canals (i.e. the gross water requirement), one should also take other factors into consideration, such as return flows and seepage losses in main canals, lateral canals and farm ditches. However, because it is not realistic to obtain records on all these factors, we cannot solely rely on the ACRES model to estimate the gross water requirement. Thus in practice, RIO-10 normally accounts around 40% of conveyance loss in calculating the gross water requirement as follows:

$$GWR = NWR / CEff \quad (14)$$

Where: GWR is gross water requirement in m^3/season;
NWR is net water requirement in m^3/season;
$CEff$ is conveyance efficiency, which is assumed as 0.71.

In actual planning, however, the above conveyance efficiency could be adjusted flexibly to keep the consistency of irrigation plans at the lateral-canal, main-canal and delta levels.

VI　Actual situations and problems in water management operation in the dry seasons 2002 and 2003

1　Introduction

The Basin and Delta Level Water Management Working Group has been engaged in activities for improving water management planning and operation in the UEB of the Chao Phraya Delta, especially at the Project and lateral-canal levels. In the course of our interviews with local officers, we realized that a lot of problems on water management, especially unfair water distribution between upstream and downstream regions, have existed for many years, but few quantitative data are ready for use to understand such problems in details. We have therefore undertaken summary studies on dry-season irrigation since 2002, in order to find any countermeasures for improving water management planning and operation. This section summarizes such studies on actual situations and problems in water management in the UEB of the Chao Phraya Delta in the dry seasons 2002 and 2003.

2 Materials and methods

The Working Group has established an e-mail report system for O&M data in February 2002 (Yuyama and Shioda, 2002). This system employed a digital data-entry form in a PDF format that was input by O&M Project Offices, transmitted as an attachment file via commercial e-mail links, and then inserted to a database at the RID Head Office in Bangkok. Since this system has been in operation, O&M data from 5 O&M Project Offices in the UEB of the Chao Phraya Delta have been accumulated in the database at the RID Head Office. Thus, the following sections mainly utilize O&M data drawn from the above database. Some supplementary data are directly obtained from RID Head Office and RIO-10.

The water allocation plans for the dry seasons 2002 and 2003 in the UEB area were prepared by the RIO-10 in November 2001 and 2002, respectively, in response to the request from the RID Head Office. Details of the planning procedures have been described in Chapter V.

3 Water allocation at the basin and delta level

Total active storage volume at Bhumibol and Sirikit dams on 1st January were 14,068 MCM in 2002 and 15,300 MCM in 2003. Therefore, according to the criteria of stored water volume at the two dams (Table 4), both the dry seasons 2002 and 2003 could be classified as "plenty" years in terms of water availability. Accordingly RID Head Office planned to release 7,000 MCM and 8,500 MCM from the two dams in the dry seasons 2002 and 2003, respectively. In 2002, the released water from the dams was then distributed to the East Bank of the Chao Phraya Delta as shown in Fig. 25.

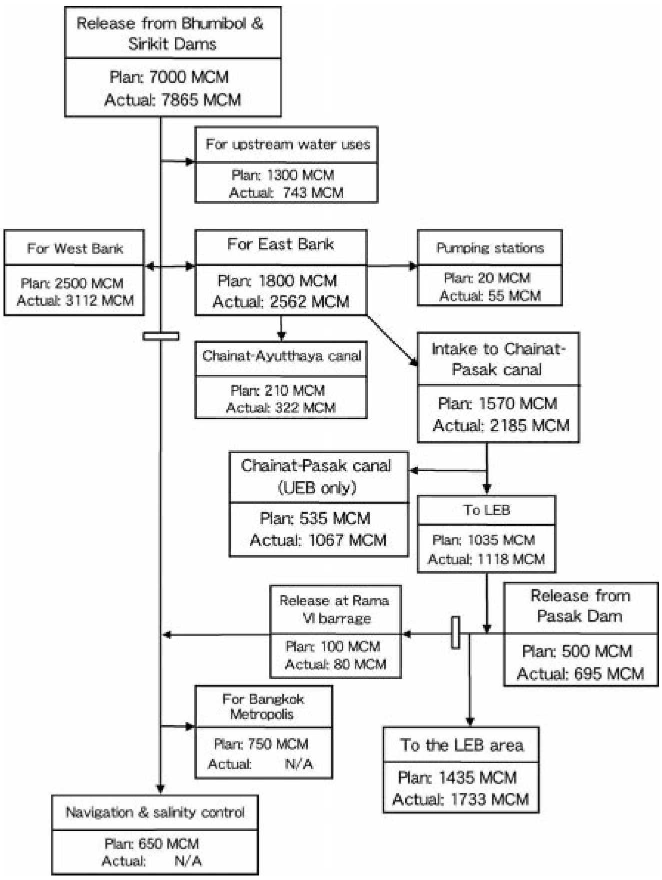


Fig. 25 Water allocation diagram for the East Bank of the Chao Phraya Delta in the dry season 2002

Actual water release from the Bhumibol and Sirikit dams in the dry season 2003 (Fig. 26) indicates two major problems. Firstly, distinctive weekly fluctuations in water release are observed. This was because EGAT would generally reduce water release at weekends to adjust to the reduction in electricity demands. Secondly, from late March until mid-April, the water release was significantly reduced to cope with the reduced demand for electricity during the Songkran (Thai New Year) holidays. As a result of such deliberate reductions in water release from the two dams, the intake discharge from the Chao Phraya River to the East Bank of the Chao Phraya Delta was forced to decline from late March to early April (Fig. 27). Unfortunately, this period coincided with the peak in irrigation water demands for dry-season paddy cultivation. Therefore the Project Offices had to work hard to distribute scarce water to paddy fields by introducing rotational irrigation and by cutting water supply at night. After the Songkran holidays were over, EGAT released more water than the plan for compensation (Fig. 26), and the UEB area was able to intake more water than the plan (Fig. 27).

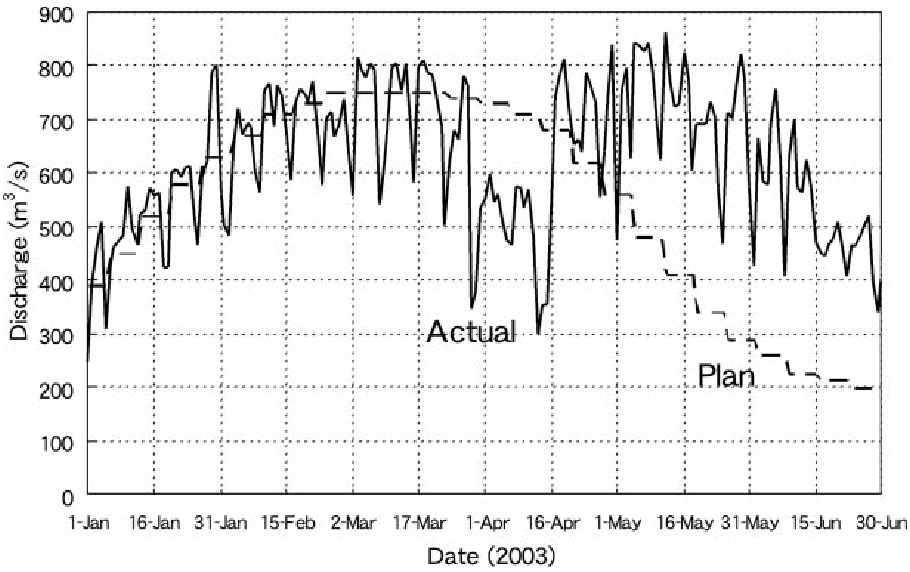


Fig. 26 Target and actual water release from the Bhumibol and Sirikit dams in the dry season 2003

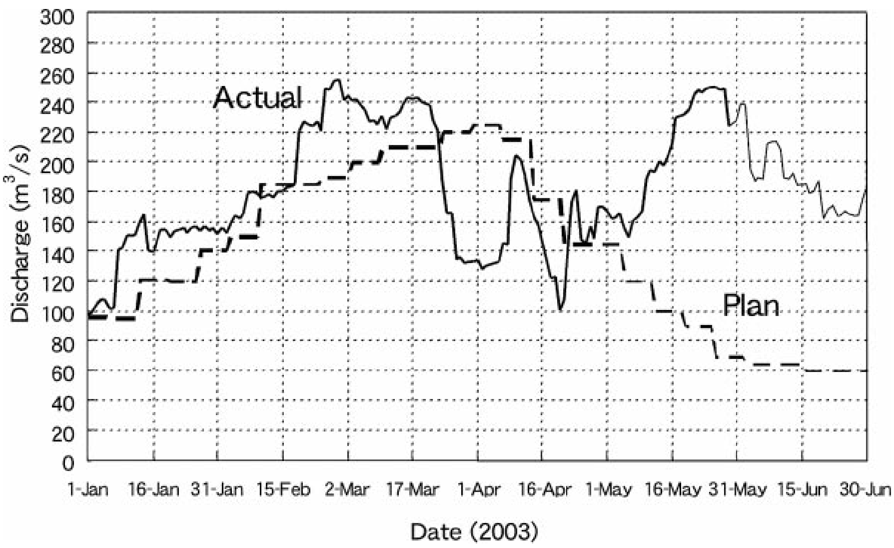


Fig. 27 Intake discharge from the Chao Phraya River to the East Bank of the Chao Phraya Delta in the dry season 2003

4 Water allocation at the Project level

Through our summary study on the dry-season irrigation, we have identified the following major problems in water allocation at the Project level:

a. Excessive cultivation of rice by farmers
b. Unfair water allocation between upstream and downstream Projects
c. The gap between target and actual water allocation patterns
d. Improper use of the pre-seasonal water allocation plan at Project Offices

a Excessive cultivation of rice by farmers

The first problem seems to be the fundamental one which has existed for many years. The officials at Project Offices always complained about this matter when we interviewed them. They said that farmers were wise enough to plant rice crops first, and then demand Project Office to send more water for sustaining the growth of already planted rice, so that the officers could not reject their plea. They said some farmers would even use pressure by politicians in order to get preferential water allocation to their own farmlands. As a result, each RID Project Office tends to divert more water to their lateral canals, wherever possible, than the allocated quota on the plan, in order to satisfy the farmers in their responsible areas. It may therefore take many years to solve this problem through transparent water management and crop diversification programs etc.

Within the UEB area, Manorom Project showed the widest gap between target and actual cultivation area (Table 12). Manorom Project has a yearly rotation on rice cultivation; for instance, in the dry season 2002, only the lower part of the Project was allowed to cultivate rice, whereas in 2003, only the upper part was allowed to do so. The farmers, however, neglected this rotational plan, and rice was cultivated in almost all parts of Manorom Project in both years, and the Project Office was forced to supply water to every lateral canal in the Project. Similarly the other Projects also showed some gaps between the target and actual cultivation areas (Table 12).

Table 12 Seasonal summary of water allocation and cultivation in the UEB of the Chao Phraya Delta in the dry seasons 2002 and 2003

Year	O&M Project Offices	Manorom	Chong Khae	Khok Krathiam	Roeng Rang	4 Projects*	Maharaj
2002	Cultivation, target (rai)	75000	88500	81700	72900	318100	101600
	Cultivation, actual (rai)	202590	190354	91390	68400	552734	233692
	Cultivation, target (ha)	12000	14160	13072	11664	50896	16256
	Cultivation, actual (ha)	32414	30457	14622	10944	88437	37391
	Cultivation, A/T ratio (%)	270	215	112	94	174	230
	Discharge, target (MCM)	116	148	134	114	512	198
	Discharge, actual (MCM)	239	249	150	145	783	309
	Discharge, A/T ratio (%)	206	168	112	128	153	156
2003	Cultivation, target (rai)	93800	89800	80000	64900	328500	236300
	Cultivation, actual (rai)	233000	177498	100079	96370	606947	395699
	Cultivation, target (ha)	15008	14368	12800	10384	52560	37808
	Cultivation, actual (ha)	37280	28400	16013	15419	97112	63312
	Cultivation, A/T ratio (%)	248	198	125	148	185	167
	Discharge, target (MCM)	151	140	108	103	502	399
	Discharge, actual (MCM)	275	215	184	157	831	454
	Discharge, A/T ratio (%)	182	153	170	152	165	114

Note:
- Cultivation area includes rice paddy field only.
- The actual cultivation area means the area under cultivation or harvest at the end of June.
- *4 Projects mean Manorom, Chong Khae, Khok Kathiam and Roeng Rang Projects.
- Disparity in discharges between Fig. 25 and Table 12 derives from water used in other sectors than agriculture, conveyance losses in the main canals, and statistical errors.

b　Unfair water allocation between upstream and downstream Projects

The second problem we identified was the unfair water allocation between upstream and downstream Projects. The dry seasons in 2002 and 2003 enjoyed plenty supply of water from the upstream reservoir dams and stable rainfall during the season that was close to the average year's one. As a result, around 150 to 160 % of the target discharges was supplied to the UEB area as a whole in both years (Table 12). However, such "excess" water was primarily taken by the upstream Project, which showed larger ratio of actual to target discharges (Table 12).

c　The gap between target and actual water allocation patterns

Thirdly, significant gaps were observed between target and actual patterns of weekly water allocation. An example of Khok Kathiam Project is shown in Fig. 28. The main reason behind this gap would be the difference in assumed cropping patterns in making the plan and the actual patterns. As mentioned earlier, the ACRES or AISP model, which RID officials use for calculating the water allocation curves, assumes that (1) farmers cultivate rice only once in the dry season, (2) they gradually start rice cultivation one after another (see Table 6), and (3) the dry-season and the rainy-season are completely separated on 1st July on the assumed cropping calendar (Fig. 29 (a)). In other words, it assumes that there is no rice cultivation area at the beginning (early February) and the end (late June) of the dry season.

These assumptions might be true some 20 to 30 years ago when the ACRES model was developed, but nowadays a lot of farmers are changing their cultivation behaviors. They try to cultivate rice twice in the dry season, and start the first rice cultivation as early as December or January. Besides, farmers do not consider 10th February or 1st July, which are the official starting and ending days of the dry-season irrigation by RID, as a special day on their cropping calendar, and just continue rice cultivation throughout most of a year (Fig. 29 (b)). Such a tendency could be observed even in a small survey conducted in Khok Kathiam Project (Fig. 30), which revealed that the sampled 19 farmers had different rice cropping calendars, and, when those individual cropping calendars were combined, the whole cropping pattern should be regarded as continuous from March to December.

In response to such a change in cropping patterns, RIO-10 somewhat modified the assumption in the dry season 2003 (Table 6 and Fig. 28), but the gap still remained (Fig. 28). Too simplified assumptions of the ACRES model would be the main cause behind this gap.

Another possible reason for the gap in Fig. 28 would be that, at the beginning of the dry season, the water must first be consumed for filling up empty lateral canals with water and then for raising the groundwater tables along lateral canals. In addition, officers at Project Offices also insisted that water must be supplied at the beginning of the dry season regardless of the cropping pattern, in order to satisfy the demands for domestic water for households along the lateral canals.

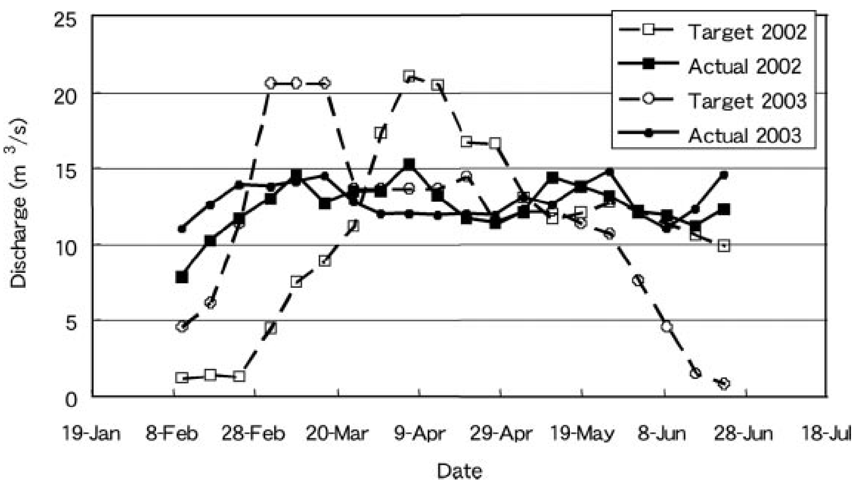
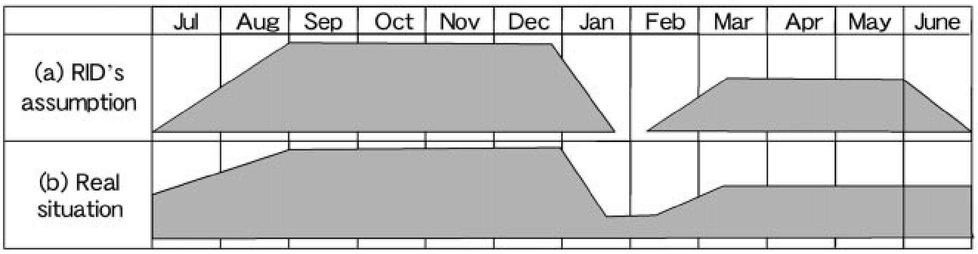
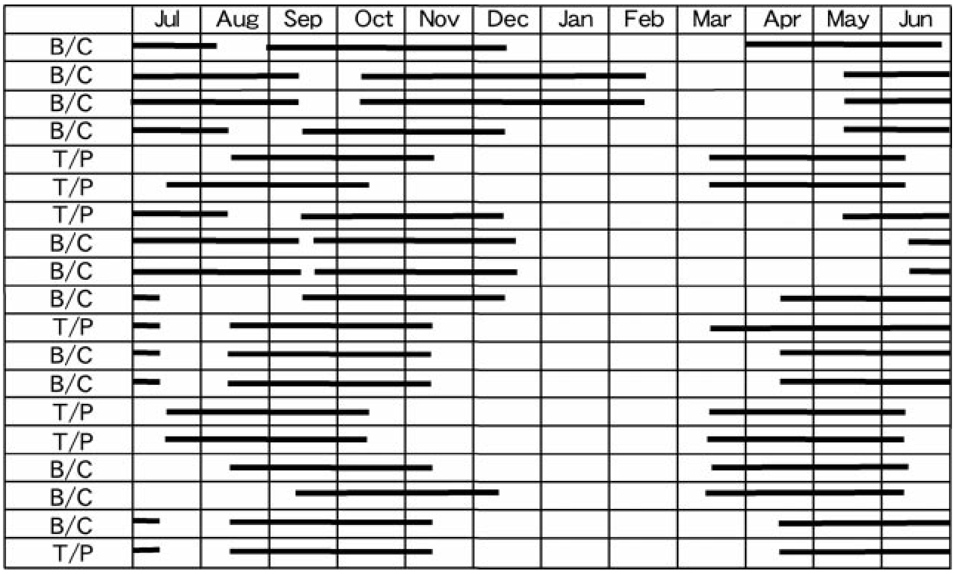


Fig. 28　Target and actual water allocation to Khok Kathiam Project in the dry seasons 2002 and 2003



Note: Thickness of the bars indicates the area under rice cultivation. The "(b) real situation" shows a rough idea based on the interviews with local officials and field observations in the UEB area. It could be modified on the basis of remote sensing data or statistical surveys.

Fig. 29 Schematic diagram of the cropping patterns



Note: B/C=Broadcasting; T/P=Transplanting
Each row shows a rice cropping calendar practiced by each individual farmer in recent years.
Source: Interviews with 19 farmers within the command area of 18R lateral canals, Khok Kathiam Project, conducted by Sakamoto in November 2003 (MWMS Project, unpublished)

Fig. 30 An example of actual rice cropping patterns in Khok Kathiam Project

d Improper use of the pre-seasonal water allocation plan at Project Offices

Our interviews with the 5 Project Offices in the UEB area revealed that they underused or almost neglected the pre-seasonal water allocation plan made by RIO-10 in operating the irrigation facilities in the dry season. The officers at the Project Offices and the RIO-10 raised the following issues:

1) Project Offices could not totally deny the requests of farmers for sending more water. Therefore the amount of water allocation must be changed flexibly during the dry season in response to farmers' requests. Using a fixed pre-seasonal plan may obstruct such flexible decision-making.
2) Project Offices did not trust the RIO-10's calculation methods for making the plan, because they considered the methods did not reflect the actual conditions of water use and cultivation in their Project areas, and therefore the plan was useless. This matter has already been discussed in Section c above.
3) Since the Greater Chao Phraya Project was established many years ago, Project Offices have conducted daily operations at the lateral-canal level without using any pre-seasonal plan. Such a long custom could not be changed instantly.
4) On the other hand, RIO-10 was reluctant to order or instruct Project Offices about the amount of water allocation to lateral canals, because they regarded it as the responsibility of Project Offices.

VII Conclusions and recommendations

1 Summary of the present problems

The present study has revealed contrasting problems in rainy and dry seasons which face the UEB of the Chao Phraya Delta. In the rainy season, the simultaneous discharge measurements and remote sensing analyses showed the importance of artificial flood controls conducted by RID in mitigating flood damages in downstream areas. By contrast, in the dry season, scarcity of water has caused several major problems on water management and cultivation as follows:

(a) The upstream Projects have got favorable water allocation over the downstream Projects.

(b) There was a wide gap between the target and actual water allocation patterns.

(c) Project Offices would not trust the pre-seasonal water allocation plan set by RIO-10, and neglect it in actual operations.

The basic causes behind the above issues were the following problems in cultivation conditions in the UEB:

(d) Farmers always try to cultivate rice more than the target set by RID. Besides, farmers have recently tried to cultivate rice twice in the dry season.

(e) In particular, the upstream Projects tend to practice more intense rice cultivation than the downstream Projects.

(f) Consequently the cropping calendar is losing its clarity, and rice cultivation is getting more or less continuous throughout a year.

It would be rather difficult to overcome the above cultivation problems, (d), (e) and (f), by RID alone: cooperation of other agencies and a long-term education of farmers would be necessary. Nevertheless, it might be possible to improve the above water management problems, (a), (b) and (c), by carrying out the following recommendations. It should be noted that the following statements are largely the opinions of the authors, and do not represent official opinions of RID.

2 Recommendation (1) - Let Project Offices decide weekly water allocation curves within the quota set by RIO and Head Office -

At present, RID takes the following approach on dry-season water allocation planning (Fig. 31 (a)):

(a) RID Head Office decides both of total water quotas to each RIO and a weekly water allocation curve at the basin level using the ACRES model, and informs it to each RIO.

(b) Each RIO then decides both of total water quotas and weekly water allocation curves for each Project, and informs it to Project Offices.

(c) In this process, Project Offices have little authority in making water allocation plan: they just have to accept and follow the plan set by RIO and RID Head Office. (Project Offices actually have a role in deciding cultivation areas in each village, but the total area is effectively controlled by RIO.)

In this study, we have seen that such a "top-down" approach is not working in practice, because Project Offices consider that water allocation curves calculated by the ACRES model are unrealistic and useless. As an alternative method, therefore, the following procedure is proposed (Fig. 31 (b)):

(a) In deciding the total water quotas throughout the dry season, the present "top-down" approach is maintained, because the total amount of water available in the dams is limited.

(b) On the other hand, in deciding the weekly water allocation curve, a "bottom-up" approach is taken instead. In this approach, when Project Office is informed the total water quota for the Project, the Project makes the weekly water allocation curve by themselves within a limit of the total quota set by RIO.

(c) Next RIO collects water allocation curves from Projects, sums them up, and submits it to RID Head Office.

(d) Then RID Head Office sums up water allocation curves of each RIO, makes a water demand curve for the upstream dams, and requests it to EGAT.

The above method is proposed because Project Offices are supposed to know the actual water-use situations in their responsible area much better than the ACRES model, as they routinely face farmers' demands for water. By following the alternative method, therefore, we may be able to make a water allocation plan more realistic. And more importantly, by inviting Project Offices to participating in the decision-making process, Project Offices would feel more

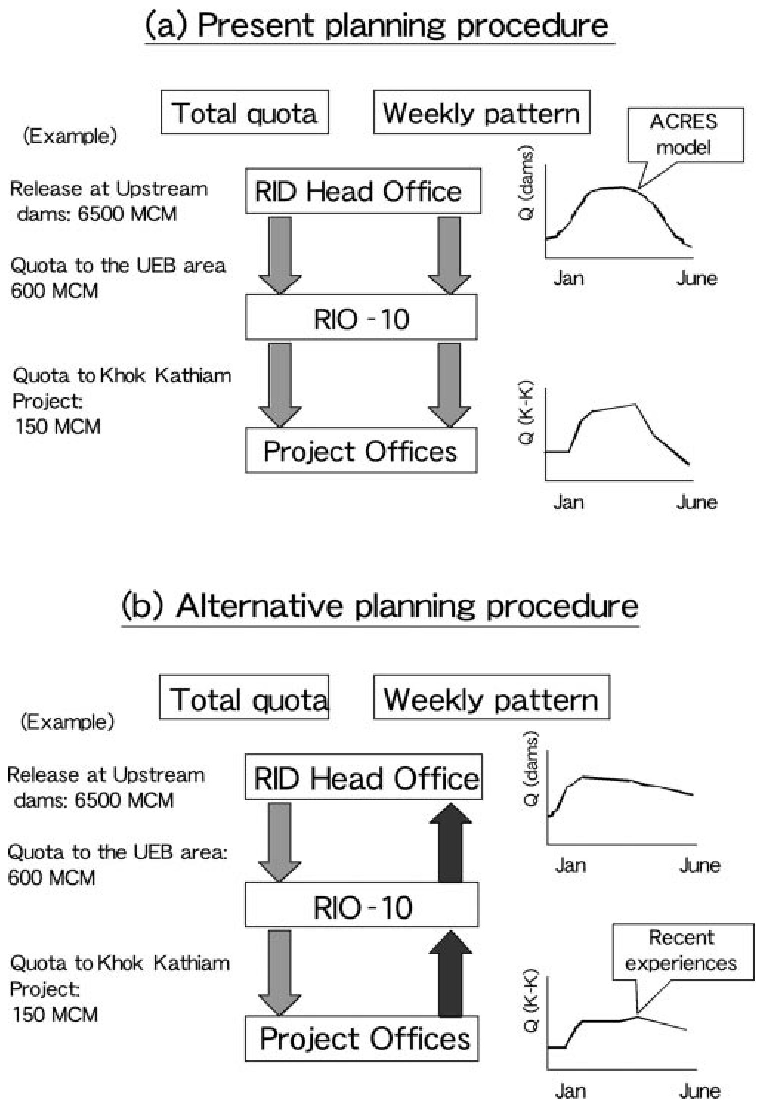


Fig. 31 Present and alternative procedures for the dry-season water allocation planning

responsible for the plan they propose by themselves.

3 Recommendation (2) - Pay attention to the plan throughout the dry season, and amend it by consensus if necessary -

In the present situation, after the water allocation plan is made, RIO-10 does not instruct Projects to follow the plan at the lateral-canal level, and consequently the plan was mostly disregarded by Project Offices. On the other hand, Project Offices claim that a non-flexible plan that cannot be changed during the dry season would be useless or even a nuisance, as they must respond to farmers' complaints and adapt to the latest water and cultivation conditions. In order to improve this situation, we would propose the following procedure for implementing the plan during the dry season (MWMS Project, 2003):

(a) RIO-10 is responsible for deciding and adjusting the quota of water allocated to each Project throughout the dry season.

(b) Project Office is responsible for deciding and adjusting intake discharges to lateral canals throughout the dry season. Nevertheless, in case the Project Office needs to change the target, the Project must get an approval of RIO-10.

(c) It would be necessary to have some formal and regular meetings among stakeholders for carrying out the above procedures smoothly, and for allocating irrigation water according to the principle of participatory irrigation management (PIM). Therefore, RID Head Office, RIO-10 and the concerning Project Offices should hold the

"Water Allocation Regulating Committee" once a month during the dry season. The Committee aims to discuss actual situations of water allocation in the previous month, and plans of water allocation in the coming month. By holding the Committee regularly, it is expected that the upstream and downstream Projects would keep a close eye to each other, and consequently each Project would be discouraged to obtain excessive water to their own Project areas, at the expense of the other Projects.

In this way, it may be possible to increase the fairness of water allocation among the upstream and downstream Projects.

In Thailand, after all, the amount of available water during the dry season is largely fixed by the rainfall in the previous rainy season. The government cannot artificially increase the amount of available water regardless of the demands of farmers, considering the difficulty in constructing new dams. Therefore, all the stakeholders should focus on fair distribution of the available water through efficient and transparent water management. The authors hope that this study would contribute toward achieving that goal.

References

1) Acres International Ltd. (1980): Chao Phraya and Meklong Basin Study, Phase 2 (in Thai).
2) Chulalongkorn University (2002): The potential and requirement for using the underground water in the upper part of the Central Plain, Seminar paper, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand, May 2002 (in Thai).
3) Kaida, Y. (1978): Irrigation and drainage: present and future, In: *Thailand, a rice-growing society*, edited by Ishii, Y., Monographs of the Center for Southeast Asian Studies, Kyoto University, The University Press of Hawaii, Honolulu, USA, pp. 205-245.
4) Molle, F., Durongdej, S., Chompadist, C., Joannon, A., and Limsawad, Y. (1999): Improvement of rice cultivation and water management in the flooded area of Central Plain of Thailand: A zoning of rice varieties by using remote sensing imagery, DORAS CENTER, Kasetsart University, Bangkok.
5) Molle, F., Chompadist, C., Srijantr, T. and Keawkulaya, J. (2001): Dry-season water allocation and management in the Chao Phraya Delta, DORAS CENTER, Kasetsart University, Bangkok.
6) MWMS Project (2003): The guideline for water management planning and operation, the Modernization of Water Management System Project, RID, DOAE, JICA, September 2003.
7) Shioda, K. (2000): A study on water management and development of flow estimation method for tidal river in the Chao Phraya Delta, Thailand, a doctoral thesis submitted to Kyoto University, Japan (in Japanese).
8) Ueda, T. and Kaida, Y. (1994): Foreign and indigenous technologies in the irrigation development of North India, *J. Japan Soc. of Irrigation, Drainage and Reclamation Eng.*, 62 (2), pp.127-132 (in Japanese).
9) Yuyama, Y. and Shioda, K. (2002): Developing a decision support system for practical water management: the Modernization of Water Management System Project in Thailand, *Rural and Environmental Engineering*, 43, pp.31-39.

チャオプラヤデルタ上流東岸域における水管理計画・運用

上田　達己*，小川　茂男**，塩田　克郎***，ARULVIJITSKUL Pongsak****，
KLINKHACHORN Phonchai****， CHOMPRADIT Chatchom**** and PUNYACHOM Athaporn****

要　約

本論文は，国際協力機構の技術援助のもと，タイ国王室灌漑局および農業普及局によって1999年4月から実施されているタイ国水管理システム近代化計画（MWMS）プロジェクトの活動の一環としてとりまとめたものである。

具体的には，MWMSプロジェクトが構築したデータベース，アンケート調査，一斉流量観測，リモートセンシング解析等を用いて，近年の水管理・耕作状況の動向を明らかにした。

本研究の結果を踏まえて，以下の提言を行った。①配水計画の策定においては，乾期全体の配水全体量の決定は，従来どおりのトップダウンのプロセスに従って，限られた水資源を地域ごとに分割していく一方，週ごとの配水パターンについては，現場の水利用実態を熟知している維持管理事務所による自主的な計画策定を認める。次に各維持管理事務所から示された週ごとの配水パターンを，従来とは逆のボトムアップ手法で積算し，それに基づいてRID本部が，上流ダムへの週ごとの放流要請量を決定する。②実際の施設運用に際して，策定された配水計画を常に参照し，必要があれば，関係者合意の上，それを変更する手続きを明確にしておく。

*農地整備部畑整備研究室
**地域資源部土地資源研究室
***タイ国水管理システム近代化計画プロジェクト
****タイ国王室灌漑局

平成17年２月４日受理
キーワード：灌漑，水田，水文，タイ，チャオプラヤデルタ，水管理，リモートセンシング