Strategy to Improve Water Management in the Chao Phraya Delta


Abstract The Chao Phraya Delta of Thailand has both problems of water shortage and flooding. There are many gaps between the ideal concept and the present methodology of water management. It is essential to achieve a stable and fair water supply for cultivation in the dry season. Available water resources for cultivation should be maintained and developed by saving water. The authors propose improving methods of water allocation planning and practical water operation, and also comment on flood control. The proposals are limited to measures that can implement within the authority of the Royal Irrigation Department (RID). The proposals refer to upstream dam operation, effective use of side flow, release from the diversion dams, water allocation for cultivation, frequent regulation of main intake regulator, effective use of rainfall in the field, and so on. Their aim is to provide useful ideas for water management based on present experience. The proposals are worthy of being implemented now, basically because they do not need much special budget allocation, they do not have any negative impact in particular, and they will contribute to carrying out water management with greater accountability. The Modernization of Water Management System Project started the development of a decision support system for practical water management to realize some of the proposals.

Key words: Stable water supply, Water saving, Hydrology, MWMS project, Thailand

I. Introduction

The Greater Chao Phraya Project (RID, 1957; Kaida, 1975; Takaya, 1980, 1982; Steve, 1995) drastically changed farming and water management in the Chao Phraya Delta of Thailand. The delta area became one of the greatest rice granaries in the Asian monsoon area. Now, rice cultivation at the level of more than five crops per two years is possible where water accessibility is good. The original purpose of the project was supplementary irrigation in the rainy season. At present, its function has extended to irrigation in the dry season, domestic water supply, and so on. Historically, only one crop in a year was possible before the project. The new trial of rice cultivation in the dry season began only about 30 years ago. The rice cultivation area increased rapidly, but soon reached its limit because of available water resources and capacity of existing irrigation facilities (Virat, 1992; Water Operation Branch, 1999).

Farming and land use in the Chao Phraya Delta have changed very rapidly again over the last 15 years (Kasetsart University et al., 1996; Francois et al., 1999a, 1999b, 2001). Water management has become more complicated and difficult than before, because water demand has in-
creased and the competition among water users has become more serious. The problems of water shortage (Chaiwat, 1994; Roongrueng et al., 1996; Sanyu et al., 1999) and flooding (Pramote, 1999) have to be examined in parallel. The authors have described the existing condition of water management elsewhere (Yuyama et al., 2000; Piphat et al., 2000).

In this report, the authors propose improving methods of water allocation planning and practical water operation for development of water resources. The aim is stable water supply in the dry season. The authors have worked for the Modernization of Water Management System Project (MWMS) (Shioda et al., 2002; Yuyama et al., 2003) at the Royal Irrigation Department (RID). Proposals in this report are limited to what the RID can implement under its own authority. To provide useful ideas for water management based on present experience is the purpose of this report.

II. Outline of Water Management in the Chao Phraya Delta

The Chao Phraya River basin is a catchment area of 162,000 km² including 1.34 million ha of

Figure 1 Outline of the Chao Phraya River basin
the low-lying delta area. The irrigable area in the delta is 1.08 million ha. Locations of main water operation facilities are shown in Figure 1. In this report, the authors call the Chao Phraya Delta the marked area in Figure 1. The Chao Phraya River system consists of four principle tributaries: the Ping, Wang, Yom, and Nan rivers. They all originate in the northern highland. The Wang River joins with the Ping River in the middle basin. Then, the Ping and Nan rivers join and form the Chao Phraya River at Nakhon Sawan; the river flows down to the lower basin through Chai Nat, Ayutthaya, and Bangkok, then finally reaches to the Gulf of Thailand. In the lower basin, the Chao Phraya River joins with tributary of the Pasak River, while the Tha Chin River diverges from the Chao Phraya main stream. The Lopburi River and the Noi River diverge from the main stream, but they join it again. The Chao Phraya diversion dam is located about 276 km upstream from the river mouth. The C2 hydrology station at Nakhon Sawan is located about 94 km upstream from the diversion dam. Figure 2 shows the longitudinal profile of the Chao Phraya River. The bed elevation and water level profiles on 21 January 1994 and 28 October 1995 are displayed. The symbols of hydrology stations below mentioned are shown in Figures 1 and 2.

Main water resources in the basin are the Bhumibol reservoir dam, with storage capacity of 13,500 MCM (million cubic meters), and the Sirikit reservoir dam, with storage capacity of 9,500 MCM. The total active storage of the Bhumibol dam is 9,662 MCM, while that of the Sirikit dam is 6,660 MCM. The total average annual inflow into the two dams is approximately 9,500 MCM. The distance between the Bhumibol dam and the Chao Phraya diversion dam is about 349 km along the river, while that between the Sirikit dam and the Chao Phraya diversion dam is about 559 km. The operation of the two dams is the responsibility of Electricity Generating Authority of Thailand (EGAT). The Pasak reservoir dam, with storage capacity of 780 MCM, began operation in November 1999. The Chao Phraya diversion dam in the Chao Phraya River at Chainat allows allocation of water to the delta area. Main intake regulators just upstream of the dam are Manorom, Maharaj, Borommathat, Phonlathep, and Makamthao Uthong regulators. They convey water to the distribution systems of Chainat-Pasak canal, Chainat-Ayutthaya canal, Noi River, Tha Chin River, and Makamthao Uthong canal, respectively.

The land elevation of the irrigable area in the Chao Phraya Delta is between 0 m and 19 m above mean sea level (MSL). Annual rainfall in the area fluctuates from 1,000mm to 1,600mm. The rainy season starts in the middle of April and ends late in October. At the beginning stage of the rainy season, it rains locally and within short periods. Non-rain days sometimes continue for quite a long period. The runoff ratio is estimated from 15 to 30%. Tidal effect comes to Phra Nakhon Si Ayutthaya (S5 hydrology station), or sometimes up to Ang Thong (C7A hydrology station).
Figure 3 Water allocation plan during the WM dry season of 2002 (January-June)

Water management is mainly carried out under the authority of the RID. The east bank of the Chao Phraya Delta is under the control of Regional Irrigation Office No.8 (RIO-8), while the west bank is under the control of Regional Irrigation Office No.7 (RIO-7). The responsibilities of the RIO are planning of water allocation, daily water operation including monitoring and reporting, flood protection, and so on. The RIO determines water operation only at main regulators. Lateral and tertiary canal levels are the responsibility of each O/M (Operation and Maintenance) Project. There are 25 O/M Projects in the delta area, including the Pra-ong Chaiyanuchit O/M Project of RIO-9 located at the lowest east bank of the delta.

To prevent conflicts over water, water allocation in the dry season from January to June is very important (RID, 1998a, 1998b). Here in after, the period from January to June is referred to as “WM dry season”, while the period from July to December is referred to as “WM wet season”. (“WM” represents water management.) Many organizations such as RID, Department of Agricultural Extension (DOAE), EGAT, and Metropolitan Waterworks Authority (MWA) regulate the water allocation plan. The Water Allocation Branch at RID Head Office (HO) estimates the total water requirement and remaining water storage as of 1 January in main dams and reservoirs. After estimating the available water volume over the next six months, a draft water allocation plan is made. Then the RID proposes a weekly plan of release discharge from the Bhumibol and Sirikit dams (hereafter referred to as “upstream dams”) to the EGAT.

For example, the Water Allocation Branch estimated that the active storage of the upstream dams on 1 January 2002 was 7,950 MCM and 6,300 MCM, respectively. Figure 3 shows the water allocation plan during the WM dry season in 2002. The total release discharge from the dams was planned to be about 7,000 MCM and the total release discharge from the Pasak dam was planned to be about 500 MCM. The remaining is retained for the following WM wet season. The
amount of water allocated for salinity control in the Chao Phraya River is about 350 MCM; for navigation, about 300 MCM; and for tap water supply, about 750 MCM. The amount of water for the irrigation and domestic use in the Chao Phraya Delta is 4,300 MCM. The Mae Klong River will divert 1,000 MCM. The side flow is not counted. RID and DOAE drafted a plan for the cultivation area, namely about 560,000 ha for rice and about 35,200 ha for upland crops in the irrigated areas where water is supplied from the upstream dams.

The total release discharge from the upstream dams during the six months from January to June varied from 1,900 to 9,600 MCM over the years from 1993 to 2001. Based on water supply, suitable rice cultivation area in the WM dry season is generally considered to be about 480,000 ha in the Chao Phraya Delta. That area is less than half of the rice cultivation area in the WM wet season. Active storage in the upstream dams of more than 8,000 MCM as of 1 January is a prerequisite condition.

III. Water Resources Development by Water Management

A master plan for water resources development considers the prospect of water demand, the technical possibility of development, and the environmental impact. Future demand is subject to economic conditions, population fluctuation, government policy on agriculture and industry, and so on. Among them, the main factor is rice cultivation area in the WM dry season. Figure 4 shows the relation among active storage in the upstream dams as of 1 January, total release discharge from the dams from January to June, and rice cultivation area in the dry season. 1.0 rai represents 0.16 ha. The rice cultivation area roughly corresponds to the active storage on 1 January and the total release discharge. Rice cultivation has exceeded the plan in most years. Over-cultivation causes water shortages. Moreover, rice production in Thailand aims not only for self-sufficiency but also for export. The rice cultivation area may fluctuate in response to the rice price in the world market.

Recent analysis (Roongrueng et al., 1996; Siripong, 1997; Sanyu et al., 1999; Francois et al., 2001) has pointed out that water resources are not actually sufficient. Much regulation and time is needed to construct large-scale dams or inter-basin water conveyance canals. Environmental impact and improvement of poor rural areas should be studied further, and public participation is a must to prioritize alternative plans of the development. On the other hand, non-structural countermeasures to develop water resources do not need much special budget allocation. They do not have any negative impact in particular. They save water through improvement of water allocation planning and practical water operation.

Figure 4 Relation between water conditions at the upstream dams and rice cultivation area

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IV. Proposal to Improve Water Management

A stable water supply at the lateral irrigation canal level in the WM dry season is essential to improve water management. It will be achieved by saving water at all spatial and temporal levels. The effect of saving water in the rainy season is higher than in the dry season. Stability is very important, because it increases the reliability between supply and demand sides in terms of organizations and people concerned. Even when water resources are not sufficient for allocation, if the information on water conditions is announced early and fair plans are made, farmers can control their cultivation plan without risk. Good water allocation planning and strict water operation will ensure them. RID is monitoring hydrology, meteorology, and water operation information at many stations and facilities daily. The first step for improvement of water management is to collect the data more efficiently and use the data more effectively. A telemetry system, if it were installed, will contribute to irrigation and drainage as well as flood control. The proposals here are considered at both the planning stage and the practical stage. At the practical stage, proposals are divided into two terms, namely the WM dry season and the WM wet season. The main focus is on the gravity irrigation system in the upper Chao Phraya Delta. Remarks are also given on flood control.

1. Proposal for the planning stage of water allocation

It is essential to make an appropriate weekly water allocation plan throughout the year. The plan for the WM wet season should be reviewed again, because it has not been given much attention recently. It is important to estimate available water resources and water demand accum-
rately. Figure 5 shows the proposed flowchart of water allocation planning. The present flowchart used by RID is modified a little. The followings are concrete proposals:

a) Upstream dam operation

The active storage at the Bhumibol, Sirikit, and Pasak reservoir dams must be basically within the respective Upper and Lower Rule Curve (URC and LRC). There have been many suggestions to modify the URC and LRC of the upstream dams (Horikawa, 1997; Sanyu et al., 1999; CTI et al., 1999; Francois et al., 2001). The RID cannot change the rule curves by its own authority. For the moment, dam operation must be considered within the existing rules. Three scenarios --of <1> Wet, <2> Dry, and <3> Normal years-- that are set up based on yearly rainfall condition should be prepared and examined as shown in Figure 6. In Figure 6, as an example, the URC and LRC of the Bhumibol dam are shown. Three water conditions are hypothesized in Figure 6. Comparison of three scenarios provides considerable differences and alternatives for dam operation. An active storage control plan is finally designed by integrated judgement based on experience. It is desirable to plan the remaining water at the end of the WM wet season to be the same as the storage of the URC based on the stability of water allocation. An example of operation of the upstream dams and Manorom regulator in Figure 7 shows the difference between planning and actual water management. Usage of the three scenarios gives an idea of the allowable flexibility of practical operations considering dam operation curves and rainfall conditions. It should be understood even at the planning stage.

b) Effective rainfall

The following four yearly rainfall scenarios should give effective rainfall for cultivation:

<1> Wet year
<2> Dry year
<3> Normal year (or average within recent 10 years)
<4> Assumption of no rain from January to June. The remaining months are the same as in <3>

Basically, the third scenario seems to be adopted at the planning stage. However, the calculation of other scenarios is desirable to understand the range of possible differences. Those scenarios are also useful at the practical water operation stage, in addition to the upstream dam operation planning and other factors mentioned below. The prediction models (Direk, 1986; Fukuda et al., 1995; Acres, 1999; Paul Consultant et al., 1999) will establish engineering baselines. The parameters in the model should be reconsidered periodically by evaluation based on observation.

![Figure 6 Conceptual operation of the upstream dam](image-url)
Inflow into the upstream dam should be calculated based on a concept similar to the above-mentioned effective rainfall. Namely, calculation cases of <1> Wet year, <2> Dry year, and <3> Normal year should be examined.

d) Effective use of side flow

Side flows from the watershed, including return flow from irrigated area between the upstream dams and the Chao Phraya Delta, can be partially used as effective water resources. The flow can decrease the release discharge from the upstream dams. The side flow can be roughly calculated as follows:

Figure 7 Operation of the upstream dams and Manorom regulator
Side flow = \( (\text{Discharge at "Nakhon Sawan"}) - (\text{Release discharge from the upstream dams}) + (\text{Consumption between the upstream dams and "Nakhon Sawan"}) \)

Here, "Nakhon Sawan" refers to the C2 hydrology station. The consumption includes water supply for cultivation and domestic use. Figure 8 shows the comparison between release discharge from the upstream dams and discharge at Nakhon Sawan in 1998.

To calculate the side flow that can be controlled and used effectively (here in after referred to as “effective side flow”) exactly is difficult. The over-estimation is dangerous for stable water supply. For the moment, it is recommendable to use the following constant base flow as the effective side flow for the safety at the planning stage of water allocation:

Base flow = Minimum \( (n) \) (Side flow)

Here, Minimum \( (n) \) is the \( n^{th} \) lowest weekly basis discharge within a period. The unit of the base flow is “MCM/week” in terms of the first arrangement of data. The authors adopted a weekly basis because the present water allocation plan is weekly and the release from the upstream dams has a weekly cycle affected by hydropower generation. The periods in a year should be divided into several terms based on runoff characteristics and irrigation patterns. The “\( n \)” is chosen by trial and error as well as by experience.

If we cannot get actual consumption data above “Nakhon Sawan”, the design value has to be used instead. If a reliable planning value does not exist, the past record calculated by water balance should be used. The regulation of over-intake for consumption above Nakhon Sawan is another problem. The minus value of calculated base flow, if any, means we cannot expect or count it as available water resources. Three scenarios of water conditions should be set up, as follows: \(<1>\) Wet year, \(<2>\) Dry year, and \(<3>\) Normal year. This is the simplest method. The estimation of base flow (Sithiporn et al., 2001) should be improved in future.

e) Release from the Chao Phraya diversion dam

In the WM dry season, the Chao Phraya diversion dam releases water for consumption, salinity control and navigation. Consumption means the intake from the Chao Phraya River for tap water by the Metropolitan Waterworks Authority (MWA) at Ban Sam Lae, Pathum Thani province. The intake discharge is almost constant. The average discharge from October 2000 to September 2001 was 46.9 m³/s. If we had unexpected inflow above the diversion dam, and could not divert it from the main intake regulators, the excess water would be released from the diversion dam. In the planning stage, a weekly water release plan from the diversion dam should be prepared based on the past record and tidal level estimated by the Hydrographic Department of the Royal Thai Navy.

f) Water allocation for cultivation
Water allocation for cultivation is the variable. It is mainly influenced by estimated active storage at the upstream dams as of 1 January, water demand for consumption, salinity control, navigation, and so on. The calculations should be continued to satisfy fair and stable water management by inputting information on a) - e) above. Computer simulations such as that by AISP (Acres Irrigation Support Package, 1999; Paul Consultant et al., 1999) give engineering baselines.

In terms of the O/M Project level, rotational irrigation method (Apichai et al., 1994) should be studied to save water. In terms of the Regional level, a weekly water allocation plan at the lateral irrigation canal level should be prepared and understood by all RID offices concerned and by farmers. The past record and experience is very important. The plan should be made public as early as possible after regulation so that the farmers can control their cultivation plan in the next season. This kind of breakdown of water allocation plan is the key point for improving water management. It will be also one of the prerequisite conditions for the crop diversification that is the present government's policy -- namely, changes of crops in the dry season from rice to field crops. Public opening and sharing of information can contribute to saving water, because unreasonable requests for water supply and illegal intake of water will decrease. Figure 9 shows the first draft of weekly water allocation plan for lateral irrigation canals 18R–22R during the WM dry season of 2002. Those lateral canal systems are for the command area of Khok Krathiam O/M Project. There was a large difference between the request by the “K-K” (Khok Krathiam O/M Project Office) and regulation by the “RIO-8” (Regional Irrigation Office No.8). Feedback on the result of regulation by the RIO-8 to each O/M Project Office and to farmers is needed.

2. Proposal for the practical water operation stage
   (1) WM dry season (January–June)
   a) Release from the diversion dams

   The Chao Phraya diversion dam releases water for downstream consumption, salinity control, and navigation. These three purposes of release interact with each other. Among them, daily consumption is almost constant.

   The present indicator of salinity control is the salinity concentration at the Memorial Bridge (C4 hydrology station) located 50 km upstream from the river mouth. The standard value is less than 2,000 mg/L. For example, EC (Electric Conductivity) was measured 35 times by the Irrigated Agriculture Branch of RID between 5 January and 14 May 2001. The EC was converted to the salinity concentration (Benchanee, 2000). The time fluctuation of the vertical and horizontal profile of EC should be surveyed several times in order to understand the phenomenon.
In the report on “Water Management in the Chao Phraya Basin during the dry season of 2000” (Water Management Branch, 2000), more release from the Rama VI diversion dam for salinity control was proposed. The proposal has been adopted from the following WM dry season.

The indicator for navigation is the minimum water depth for big boats along the course. Therefore, water level and bed level profiles along the river should be arranged. When the needed water depth cannot be maintained, a warning must be issued.

For the moment, the process and grounds for determining the release discharge from the diversion dams should be reviewed. The release discharge from the Chao Phraya diversion dam and the Rama VI diversion dam is measured at C13 and S26 hydrology stations, respectively. Monitored information should be summarized for decision-making on the dam operation. Figure 10 shows the sample layout of information. More quantitative study is needed to clarify the relation among release discharge from the dams, tidal level, water levels along the river, and salinity concentration. The study needs to include the diversion from the Meklong River. Discharge at the main points in the Chao Phraya River can be estimated using the flow analysis model (Takaki et al., 1994; Shioda et al., 1992a, 1992b).

b) Effective use of side flow

The buffer function of the river makes it possible to store more water brought by uncertain rainfall and runoff from upstream watershed in the Chao Phraya River above the Chao Phraya diversion dam. If increase of the water level is 30 cm along the river (which is 400 km long in total and 200 m in width), and the water level at the upstream end is the same, the storage capacity in the river would be 12 MCM. This volume is roughly equivalent to the release discharge from the upstream dams of 500 m³/s over 6.5 hours. For more accurate calculation, a flow analysis is required using cross-section data and a Q-h curve at hydrology stations along the river as well as the observed hydrological data.

Figure 10 Summary information on the diversion dam operation in the WM dry season
Release from the upstream dams should be minimized by monitoring the trend of runoff. In this sense, close and quick communication between RID and EGAT is required. The present process for modifying dam operation takes much time and cannot achieve the effective use of side flow in time. A change in the process and the balance of authority between RID and EGAT, and quick estimation of runoff by RID, must be considered. At the same time, the traveling time between the upstream reservoir dams and the Chao Phraya diversion dam under various conditions must be studied to support the dam operation.

c) Frequent regulation of the main intake regulator

EGAT decreases the release discharge from the upstream dams on holidays, because electricity consumption is lower. Its influence reaches Nakhon Sawan on the Chao Phraya River, as shown in Figure 8. This means that main intake regulators located just upstream of the Chao Phraya diversion dam, such as Manorom regulator, have to change their gate opening length to maintain weekly allocated intake discharge. More frequent regulation is recommendable. The traveling time of 18 hours between C2 hydrology station at Nakhon Sawan and the Chao Phraya diversion dam was measured by float on 11 October 1996. The time is longer under low water level conditions in the WM dry season. The discharge at Nakhon Sawan, the needed release discharge from the Chao Phraya diversion dam, and the allocated weekly discharge for the delta should be carefully compared daily.

d) Operation of main regulator along the main irrigation canal

The sill elevations of some intake gates to lateral irrigation canals along the main irrigation canal is relatively high. This hardware condition cannot be changed for the moment. Therefore, the target upstream water level at the main regulator must be high. The present operational indicator for the regulator is not the discharge but the upstream water level. However, the pass-through discharge of each regulator should be controlled to meet the water requirement downstream. Such operation will increase irrigation performance and efficiency. Operation guidelines used by “Nuflow” (IEC, 1995; Yoshino et al., 1997) are helpful to determine the regulator operation in the Chainat-Pasak canal system and meet the influence of the Manorom regulator operation during the transit period of operation. The usage of pumps should be also examined, to determine whether it would be an advantage to set the target upstream water level at the main regulator lower than that at the present target level.

e) Effective use of unexpected discharge from the main intake regulator

The planned intake from the Manorom regulator in the WM dry season of 2000 was 1,046 MCM. In this season, the rain started earlier than in a normal season. The water level at the Sirikit reservoir dam reached near that of the URC from the middle of May. EGAT released more water than under the plan because of high demand for electricity. This caused an increase in discharge at the Chainat-Pasak canal. As a result, the practical intake became 1,666 MCM. The situation is shown in Figure 7. This kind of unexpected allocation beyond the primary plan can increase available water resources. If there is empty space in small ponds, in a drainage canal, or even in a lateral irrigation canal, the excess water should be stored for the use in the following weeks. However, the increase in water level should not be too rapid, to prevent the collapse of the ponds and canals.

f) Effective use of rainfall in the field

Even in the dry season, we sometimes have rainfall of more than 20mm/day. The rainfall is local (Yuyama et al., 2002a). The reducible amount of water in the following day or the
following week should be stored upstream of the Chao Phraya diversion dam by controlling main intake regulators and intake gates along the main irrigation canals.

(2) WM wet season (July–December)

a) Upstream dam operation

A supplementary supply of irrigation water from the upstream dams is needed even in the rainy season. The rice cultivation area in the WM wet season is more than twice that in the WM dry season. The release should be minimized, because we have rainfall in the field and runoff upstream of the Chao Phraya diversion dam. It is essential to operate the upstream dams following the designed active storage control plan for that year. The release for the hydropower generation should be within the total water requirement downstream of the dams. The trend of inflow discharge into the upstream dams must be carefully monitored to prevent flood damage.

b) Effective use of side flow

Effective use of side flow into the Chao Phraya River and the Chao Phraya Delta enables us to keep more water in the upstream dams. The trend of flow conditions can be used to regulate upstream dam operation in the following weeks. The discharge at Nakhon Sawan and total amount of weekly-allocated discharge for the delta should be carefully compared. More strict estimation of traveling time contributes to determining the desirable release discharge from the upstream dams. Monthly estimation of side flow based on the trend of discharge in the river and accumulative rainfall is also useful. Especially, if floodwater from the Wang and Yom Rivers that have no reservoir dams could be estimated, the release from upstream dams could be reduced.

c) Effective use of rainfall in the field

Effective use of rainfall in the field in the WM wet season is more important and realistic than that in the WM dry season. The procedure for saving water is the same as the above-mentioned procedure in the WM dry season.

3. Remarks on flood control

a) Release from the upstream dams

The estimation of inflow into the upstream dams and the monitoring of flow/inundation conditions are important. The review of the Sirikit dam operation in 1995 gives us good suggestions. In those days, the water level of the dam became higher than the URC, and the dam had to release the same amount of inflow even though the downstream area had already been inundated. This fact tells us the importance of an integrated monitoring system and a powerful decision support system for dam operation among related organizations including RID and EGAT.

b) Buffer function of floating rice area for flood mitigation

Today, the location of flooding areas in the Chao Phraya Delta is almost completely controlled by water operation. Scattered inundation prevents serious damage. Problems of flooding often occur in October and November. Paddy fields cultivating HYV (High Yield Variety) cannot receive so much water during floods. However, a floating rice area has some possibility to receive surplus water for flood mitigation. The stem of the floating rice increases from 2 m to 5 m according to water conditions. The cultivation calendar of the floating rice matches natural water conditions. The harvest starts in December or January, after the standing water is drained.

Floating rice was cultivated in 114,000 ha in 1997 (CTI et al., 1999). Its storage volume is estimated at 2,200 MCM by assuming that water depth is 2.0 meters. Without a floating rice
area, protecting Metropolitan Bangkok from flooding would be impossible. Each unit of floating rice area -- a so called "drainage box" -- has a drainage regulator to control water level. Suppose we could convey surplus water to the floating rice area at the peak flood time with a depth of 15 cm (3cm/day × 5 days); the total storage capacity would be 165 MCM. We can call this a buffer function. That volume is equal to an inflow discharge of 640 m³/s within five days.

c) Flood buffer function of rivers and canals
   Recently, water levels and flow conditions of main rivers and canals can be controlled to some degree by the operation of diversion dams and regulators along both main irrigation and drainage canals. The river and canal network also has a buffer function for flood mitigation. If the rivers or canals upstream and midstream can store surplus water temporarily, they contribute to cut off a peak discharge. Suppose a river or canal with the length of 100 km and the width of 200 m could increase water level by 30 cm without any damage of overflow or break of embankment; the storage volume would become 6 MCM. This volume is equivalent to 70 m³/s, but it is effective only for a day. That is realized by conveying excess water in the Chao Phraya River to the Lopburi River, the Noi River, and main irrigation and drainage canals. The volume itself is not so large relatively. However, the function of controlling the timing of releasing surplus water to the downstream of the Chao Phraya River is significant, because the lower Chao Phraya Delta is a flood-prone area affected by high tides. Moreover, the function of the river and canal network that conveys surplus water to the floating rice area is important.

d) Inflow from out of a command area
   RID had to break the embankment of the Chainat-Pasak canal in 2000 to decrease inundation of the left bank area. The left bank of the canal is out of a command area. Development is still going on there. The peak discharge will be larger and the traveling time of runoff shorter than now. When a large amount of inflow is predicted, the intake from the Chao Phraya River at the Manorom regulator should be decreased. Present poor monitoring of conditions in the outside of command area should be improved.

e) Timing of release from the Chao Phraya diversion dam and the Rama VI diversion dam
   The main indicators for dam operation are water level at the C2 hydrology station at Nakhon Sawan, upstream and downstream water levels of the diversion dams, water levels downstream of the Chao Phraya River including the C12 hydrology station at RID HO, and tidal level at Samut Prakan. The dams can be operated appropriately based on the above information. This is an advantage of the Chao Phraya Delta, because of its slow water flow phenomenon. However, the process should be recorded as much as possible to transfer the decision-making experience from senior engineers to the young generation.
   On the other hand, support by mathematical model simulation (Takaki et al., 1994) is also needed. It is desirable for the model to deal with overflow or inundation. Release discharge from the diversion dams is the upstream boundary condition, and tidal level is the downstream boundary condition. Recently, hydrodynamic flow measurement, risk analysis (Tawatchai, 1999), and a neural network model (Tawatchai, 2000) have been introduced. However, the unsteady flow analysis is still important basic knowledge. Through the modeling and diagnosis of flow conditions, engineers can understand what is happening in the field. They can also find out how to improve water operations.

4. Implementing the proposals
   The RID can try most of the above-mentioned proposals. The MWMS Project has already
begun some activities. The decision support system for practical water management is under development (Yuyama et al., 2002b). It is expected to provide summarized information to all the related RID offices and farmers. The Water Allocation Branch and the Water Allocation and Operation Center at RID HO need to show good leadership in cooperation with the Water Information and Forecast Branch, Regional Irrigation Office, O/M Project Office, Hydrology Center, EGAT, DEDP, farmers, and so on.

We do not have any objective function to evaluate water management, even when we limit it to water allocation for cultivation. The target is not necessarily to maximize the total cultivation area. The price of rice, safety from flooding, stability of water allocation for the next several years, fairness and equality of water allocation throughout the year, and efficiency of water use must be considered together. Generally speaking, the improvement of any one of them has influences on the others. This is the difficulty in water management.

The upstream dams are operated by a carry-over system. The engineering side (including the authors) have to respect political decisions. For example, in 1999, although the remaining water storage in the upstream dams was very low and should not have been allocated for the dry season’s cultivation according to the criteria, the RID accepted a plan to cultivate 300,000 ha to mitigate the economic crisis. The water management in 1999 was actually difficult. However, the water shortage was cleared owing to a lot of rainfall in that year. If 1999 had been a dry year, serious water conflict would have occurred in 2000. That is why some scenarios of water conditions are necessary for water allocation planning and practical operation, as demonstrated in Figure 6.

The authors paid special attention to the stability of water management in this report. Therefore, for example, the proposal for upstream dam operation came to the conclusion that the remaining water at the end of the WM wet season should be the storage of the URC. This concept has to decrease the efficiency of water use and is subject to the uncertainty of rainfall conditions. Therefore, it is more realistic to discuss desirable storage at the beginning of the WM wet season, namely on 1 July. We may say that the ideal upstream dam operation as a result is to match the URC at the end of the WM wet season and the LRC at the end of the WM dry season. In terms of recommendable active storage at the beginning of the WM wet season, Francois et al. (2001) suggested that 2,500 MCM is enough to avoid crises, while the active storage by the LRC on that day is about 6,000 MCM. The operational rule must be designed according to the priorities of water management.

V. Conclusion

The Chao Phraya Delta of Thailand has the problems of water shortage and flooding. To minimize the gaps between ideal concept and present methodology in water management, it is essential to achieve a stable and fair water supply for cultivation in the dry season. Available water resources for it should be kept and developed by saving water at all spatial and temporal levels.

In this report, the authors proposed improving methods of water allocation planning and practical water operation. The proposals addressed upstream dam operation, effective use of side flow, release from the diversion dam, water allocation for cultivation, frequent regulation of main intake regulator, effective use of rainfall, and so on. The proposals are worthy of implementation now, basically because they do not need much special budget allocation, they do not have any negative impact in particular, and they will contribute to carrying out water management with greater accountability. The decision support system for practical water management is under development in the MWMS Project to realize some proposals. Suppose we can get new water resources of 5–10 % of recent release discharge from the Bhumibol and Sirikit dams in the
WM dry season of 7,000 MCM. This is equivalent to the water demand for a rice cultivation area of about 35,000–70,000 ha. It can also increase the flexibility of water operations.

A suitable weekly water allocation plan, strict water operation at the main irrigation canal system level and lateral irrigation canal system level, and flexible water operation at the basin and delta level are essential to improve water management and to overcome the constraints on water management.

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