Phumiphon Dam Operations during the 2011 Thailand Flood

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INTRODUCTION

In October 2011, as a flood approached Bangkok, the Phumiphon Dam, one of the Thailand's largest dams upstream of Bangkok in Chaophraya River basin, was nearly full and a large amount of water was discharged. Sirikit Dam that has the largest capacity after Phumphon Dam in the basin also continued heavy discharge of water from August to late September. That rapid and substantial discharge from the two largest dams was criticized strongly by Thai society as having exacerbated or even directly caused the flooding in and around Bangkok. The cause of the massive discharge was speculated to be faulty operation. It was even suspected by some to be a conspiracy involving the deliberate storage of water by a particular political group. In response, the Electricity Generating Authority of Thailand (EGAT) overseeing both dams immediately published a statement (EGAT 2011) on November 1, 2011 to deny any misconduct in its dam management. Nevertheless, the incident and its causes have not been understood well by the general public. This chapter is intended to facilitate the understanding of flood control measures currently taken by the Thai government by examining the Phumiphon Dam operations at the time of the 2011 flood, based on operational rules and past cases of operation, and by describing the operation rules as they have been revised after the flood, in addition to actual operations in 2012.

One reason for such increased public attention to the Phumiphon Dam at the time of the 2011 flood is undoubtedly its enormous size. The Phumiphon Dam storage capacity is approximately 13.5 billion cubic meters, nearly half of Lake Biwa's water volume of 27.5 billion cubic meters (cbm.). The immensity of the dam can be imagined also from the fact that the largest storage capacity in Japan, that of the Tokuyama Dam, is 0.66 billion cubic meters. Because of that huge capacity, people's high expectations for flood control and disappointment with the failure and fear of the vast amounts of water can be readily imagined. The beginning of the large water discharge in early October coincided with the approach of flood waters to areas around Bangkok, creating conditions that have encouraged the blaming of dam operations for the flooding.

The mere existence of the Phumiphon and Sirikit Dams alone, however, is insufficient to contain all floods that occur in Bangkok and the surrounding Chaophraya Delta.

The catchment area of 26,386 square kilometers covered by the Phumiphon Dam constitutes only 16% of the entire basin area of the Chaophraya River covering 160,000 square kilometers. Even with the Sirikit Dam, another large dam in the Chaophraya River basin having storage capacity of 9.5 billion cubic meters, the total catchment area comprises a mere 30% of the entire basin. Despite the operation of other dams on the Chaophraya River, their storage capacity is substantially less than those of the Phumiphon and Sirikit dams, limiting their effectiveness for controlling the seasonal rise in the water level in downstream areas, as described later. Inundation inside levees caused not by flooding of large rivers but by poor drainage in the area around Bangkok is another factor contributing to flood damage. In fact, the Chaophraya Delta experienced heavy flooding in 1983, 1995, and 2006. Particularly in the 1983 flood, adequate reservoir capacity of both the Phumiphon and Sirikit dams was left unused and downstream discharge was minimized during the flood. The area around Bangkok suffered another period of wide inundation in 1995, during which the amount of discharge from the Phumiphon Dam was also limited.

The operational rules for all major dams in Thailand, including the Phumiphon Dam, were revised after the massive flood of 2011. However, downstream areas might still overflow, as noted above, even with the maximum capacity of the existing dams. For that reason, various flood control measures described in Sucharit [2015] are implemented simultaneously.

The following Section 1 examines whether the management and operation of the Phumiphon Dam were appropriate during the 2011 flood. Section 2 explains the objectives and methods of the revision of operation rules conducted after the 2011 flood. Section 3 subsequently describes the order of water supply in the Chaophraya Delta as the basis of the Phumiphon Dam management and operation rules and changes in such orders, and examines the impact on society of the revised management and operational rules after the 2011 flood.

SECTION 1: The Phumiphon Dam and the flood of 2011

1. Dam and flood control

Before describing the Phumiphon Dam, which is not well-known in Japan, and flooding related to the dam, the following briefly explains flood control using a general dam in the case of Japan.

Dam flood control is intended to retain some water temporarily from river runoff (flood) that might overflow in a dam. Dam discharge is reduced if the river flow exceeds a certain level (inflow > outflow). When the flow is below a certain level and there is no longer a risk of overflow, an amount of water greater than the inflow is discharged to release the water stored in the dam (inflow < outflow). This cycle of water storage and discharge reduces fluctuations in the flow downstream of the dam and reduces the risk of river flooding caused by a rapid rise in the water level. The greater the free space (flood control capacity) when starting flood control, the more the downstream discharge can be reduced, thereby improving the flood control function. Therefore, considering flood control only, the amount of stored water (effective storage) should be minimized when not controlling floods. An example of this is a dry dam (or flood-control dam), in which water is not stored at all when the flow is less than a certain volume. Actually, however, few such dams used exclusively for flood control (flood prevention) exist today. Many dams that have flood prevention functions, including the Phumiphon Dam, are used multifunctionally also for power generation and agricultural purposes such as irrigation. An extremely important aspect of dam operation is therefore manipulation of the water level to serve the purposes of flood prevention and irrigation simultaneously.

The flood control capacity of a dam is an important aspect of flood prevention planning for each basin. River flow exceeding the assumptions in such a flood prevention plan, however, exhausts the dam's flood control capacity. Storage of water (flood control) is halted before the reservoir becomes completely full and the water flows over the dam because such a situation might result in contingencies including damage or collapse of the dam. In other words, the operation is shifted to downstream discharge of the same amount of water as that which flows into the reservoir. Such discharge operation is an exceptional case in dam operations that are intended for flood control. In Japan, that policy of discharge operation is called "proviso operation" as it is specified in a proviso to dam operation rules.

Two aspects in this proviso operation, however, require particular attention. The proviso stipulates that the amount of outflow be equal to the amount of inflow, i.e., the river runoff is only passed through the dam. Therefore, the condition is simply returned to the state that prevailed before the dam's construction. The operation discharges an amount of water that is less than the amount of inflow before the reservoir is full. When the reservoir is full, it merely restores the condition equivalent to non-existence of the dam. Another concern is that the proviso operation is implemented, as noted above, when the river runoff exceeds the amount assumed in the flood prevention plan. Whereas flood prevention plans in Japan generally cover a very large stream flow that theoretically occurs once in 50–100 years, it is only a matter of probability. The potential for river outflows greater than such assumptions caused by torrential rains and other causes is widely acknowledged.

In principle, therefore, the "proviso operation" is executed in response to force majeure and does not aggravate flooding. Nevertheless, it often becomes a target of social criticism even in Japan. In the process of shifting from normal flood control operation to the proviso operation, outflow increases from an amount below the inflow to the same as the inflow. This certainly causes the downstream water level to rise, resulting in misunderstanding about the first aspect above. The proviso operation that discharges water from the dam into a river that is already flooding is perceived as aggravating the flood damage. Generally speaking, residents expect that a dam functions as a flood-control measure when the river overflows, and discharge of a large amount of water precisely at times of flooding tends to be viewed as an error in dam management and operation. This is the conflict in the second aspect. It might be regarded as a difference in opinions about the responsibility theory as to the extent of responsibility of river and dam managers in natural disaster prediction and damage prevention. In one case, residents of an area downstream of a dam, who had suffered damage from inundation amid proviso operation, filed a lawsuit against the river and dam operators, claiming that the dam management rules were defective and that there was negligence in its operation.

As described at the beginning this chapter, the Phumiphon Dam had little room to maneuver left at the time of the 2011 flood. The amount of discharge had been increased significantly. Whether this is considered proviso operation or not will be discussed precisely in Paragraph 3 of this section, but it is evident that the condition was at least similar to that of proviso operation. In addition, social criticism directed to the operation resembled criticism directed at proviso operation in Japan, aside from the conspiracy theory, including “flooding aggravated by the discharge” and “discharge being an operational error or negligence in the management.” Therefore, the propriety of the Phumiphon Dam operation in the 2011 flood can be assessed based on the following two issues in light of the above principles of proviso operation. First is whether the amount of outflow exceeded the amount of inflow and then the extent to which the discharge controlled the flood. These will be discussed in Paragraph 3 of this section through analysis of the amounts of inflow, outflow, and storage of the Phumiphon Dam before and after the massive discharge in October 2011. The other aspect requiring attention is whether the amount of inflow in 2011 exceeded the assumption in the plan and whether measures to increase the discharge were a result of force majeure. This includes the questions of whether the amount of inflow was difficult to predict, whether the capacity for flood prevention was secured as stipulated, and whether a particular operation that might invite danger was conducted. These points will be discussed in Paragraph 3 of this section through analysis of the water storage operations of 2011.

2. Overview of Phumiphon Dam

(1) Phumiphon Dam Specifications

Phumiphon Dam is a multipurpose dam used for power generation, agricultural and industrial water supply, retention of river water levels for navigation, and other purposes. Construction of the main body began in 1953. The dam was completed in 1964. Upon the request of the Royal Irrigation Department of Thailand, the U.S. Bureau of Reclamation surveyed and analyzed the hydrological and geological features and power supply of the construction site and prepared relevant reports. In 1957, Yanhee Electricity Authority was established as an organization wholly owned by the Thai government; it took charge of dam operations in 1961. Yanhee is now a part of the Electricity Generating Authority of Thailand (EGAT), which manages and operates the dam under the direction of the government committee.

The World Bank's loan report at the time of the construction listed power generation, agricultural water supply, and water level retention for navigation as expected benefits of the dam. The World Bank provided a 66 million US dollar loan for the first-phase project in 1957 and an additional loan for the subsequent power supply project (second-phase project).

The size of the main body of the Phumiphon Dam is nearly equivalent to that of the Kurobe Dam in Japan, with height of 154 meters (elevation of the crest above sea level is 261 meters), length of 486 meters, and crest width of eight meters. The body type is an arched concrete dam, which is the same as the Kurobe Dam.

The Phumiphon Dam has two discharge channels: a sluiceway for power generation and spillways. The sluiceway for power generation, which consists of eight tubes placed in the main body of the dam, is used to operate eight generators installed directly under the dam body. The total discharge capacity for power generation of the eight tubes is as high as 60 million cubic meters per day (average of 694 cubic meters per second). The total power generation capacity is 780 megawatts. Generator No. 8, which functions also as a pump, is used to generate hydroelectricity by pumping up the water stored between the Phumiphon Dam and the downstream secondary dam (the Ping River downstream dam) into the Phumiphon Dam.

Photo: Phumiphon Dam from the crest. Eight outlets from the dam body (center) connected to the power house (bottom right) are seen (September 22, 2012 by the author)

The spillways constitute an emergency discharge channel that is used when outflow through the normal channel (the hydroelectric sluiceway for the Phumiphon Dam) is inadequate for proviso operation (equalizing outflow to inflow). They are designed to have adequate capacity for delivering the flood flow. The Phumiphon Dam spillways have four tunnels with diameter of approximately two meters dug into the mountain on the right bank of the dam body. The spillway capacity is up to 6,000 cubic meters per second (approximately 500 million cubic meters per day). The largest inflow in 2011 was approximately 290 million cubic meters per day on October 14, which was less than 60% of the maximum flow capacity of the spillways. Hydroelectric discharge fundamentally becomes the entire amount of discharge if the level or amount of water is below that for using the spillways.

(2) Basic operational rules for the Phumiphon Dam

The maximum and minimum amounts (or levels) of water storage to be complied with are specified every month at the Phumiphon Dam. The water is reserved and released to maintain storage within this range. The time-series curves to express these upper and lower limits are respectively called an upper rule curve and a lower rule curve.

Both curves are at the lowest point at the beginning of the rainy season. They reach the peak at the end of the rainy season because, for irrigation purposes, water must be reserved at the end of the rainy season to the greatest extent possible for the upcoming dry season. For flood prevention, free space must be reserved at the beginning of the rainy season. Lowering the upper rule curve increases the free space for flood control and raises the safety level, but it reduces the amount of water stored at the end of the rainy season while increasing the risk of shortage of agricultural water during the dry season. The rule curves are determined based on the balance between the priority on irrigation and that on flood control.

The water is released additionally depending on the reservoir level (elevation of the reservoir water level above sea level) if a large flow into the dam raises the reservoir level to almost 259.5 meters (the maximum reservoir level is 260 meters; its effective storage is 9,662 million cubic meters) and the inflow continues. The manual instructs operators to discharge 30% of the inflow when the reservoir level reaches 256 meters, 50% at 257 meters, 70% at 258 meters, and 100% at 259.5 meters (EGAT 2010). This

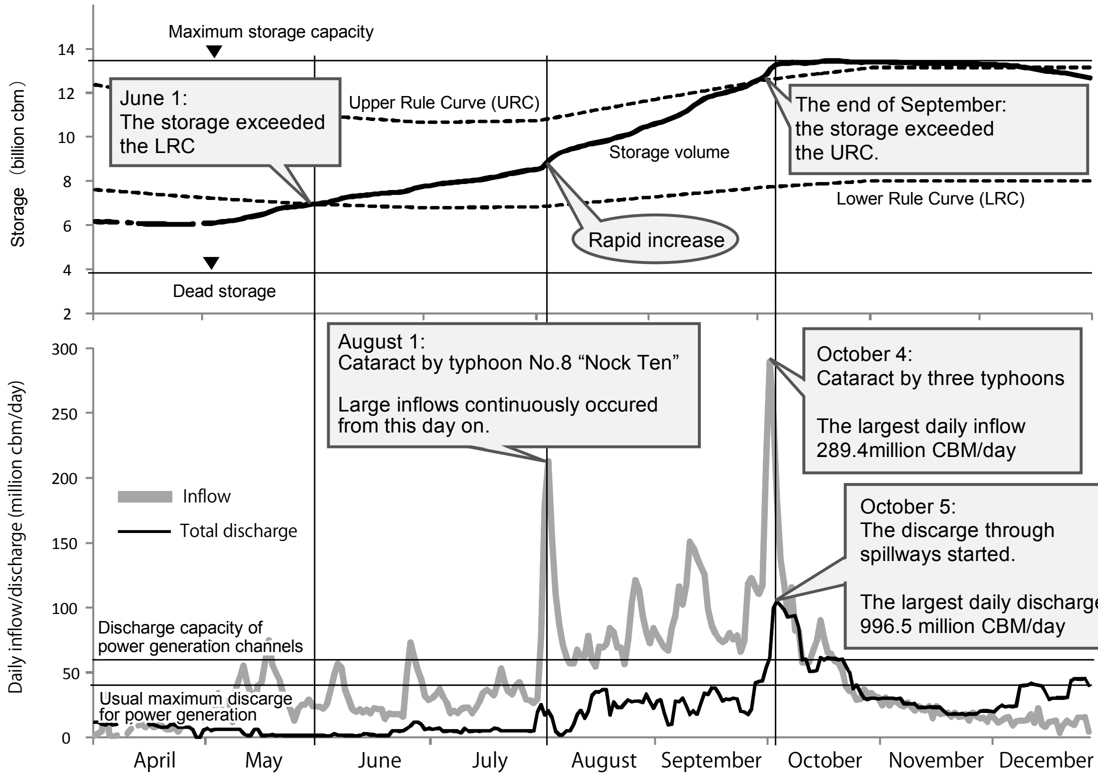
100% discharge is fundamentally equivalent to “proviso operation” in Japan. If the amount of discharge necessary for 100% discharge exceeds the maximum hydroelectric discharge capacity, then water must be released from the spillways.

The actual amount of discharge is chosen, based on the rules above, by a committee that meets at the Ministry of Natural Resources and Environment and Ministry of Agriculture and Cooperatives on every Monday and Tuesday, respectively. This committee consists of related government agencies and organizations including the Royal Irrigation Department and Electricity Generating Authority of Thailand (EGAT) and determines the daily amount of discharge from the Phumiphon Dam and other large dams in Thailand for the week (according to an interview at the Royal Irrigation Department). Daily discharge schedules made by the committee are sent to each dam once a week. Detailed changes might be notified to operators later in the middle of the week depending on various conditions.

3. Events of 2011

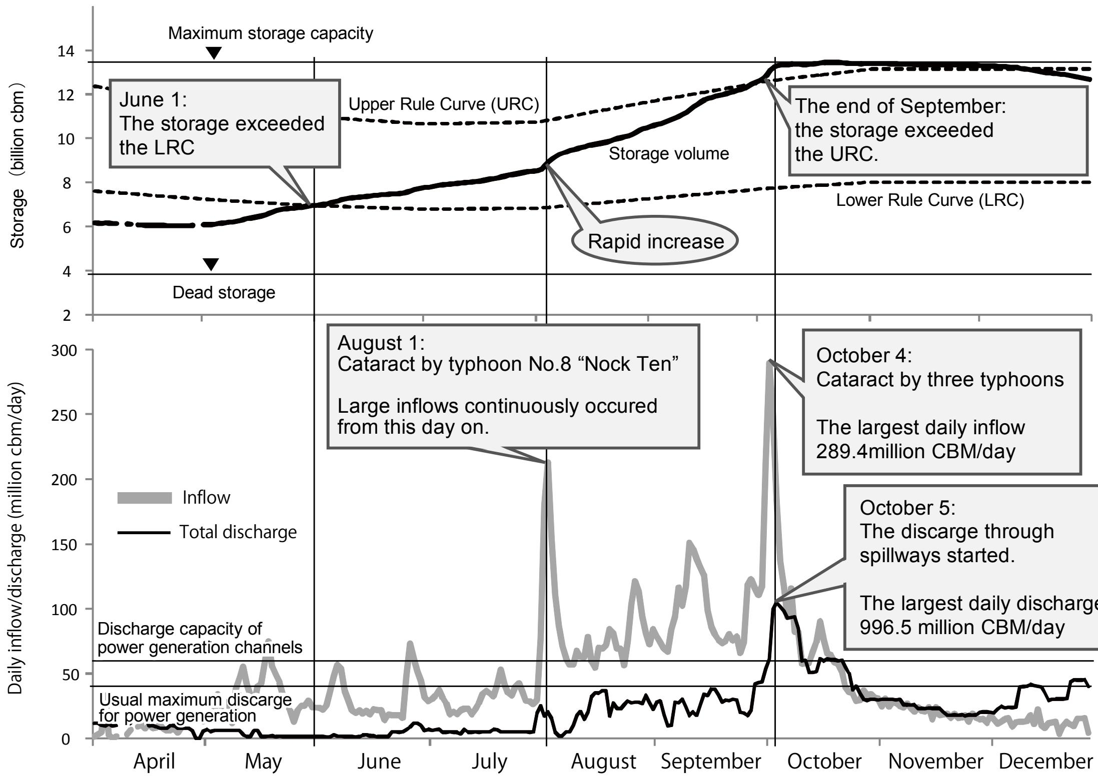
The following examines details of the data on the dam operation and flow in October 2011 by comparing them against the operation rules to investigate whether the large discharge of dam water at the time is an unavoidable measure to prevent the collapse of the dam itself, and also whether the discharge exceeded the inflow and whether the operation and use conformed to the relevant regulations.

Figure 1 exhibits the amounts of inflow, total discharge, and water stored during April–December 2011. In the data presented above, Figure 2 magnifies the section from around the beginning of October, when the large discharge at issue occurred.



(Source) Created by the author based on Hydro and Agro Informatics Institute (http://www.thaiwater.net/web/) and Electricity Generating Authority of Thailand (EGAT) [2010])

Figure 1: Amounts of inflow, total discharge, and water stored during April–December 2011



(Source) Created by the author based on Hydro and Agro Informatics Institute (http://www.thaiwater.net/web/) and Electricity Generating Authority of Thailand (EGAT) [2010])

Figure 2: Amounts of inflow, hydroelectric discharge, discharge from the spillways, and water stored during April–December 2011

May 1: The total amount of water stored at this point was 6,076 million cubic meters, substantially below the standard daily amount of 8,043 million cubic meters determined by the lower rule curve.

May 13: From this day on, the daily amount was reduced to approximately 1.5 million cubic meters. The water level gradually increased and exceeded the lower rule curve between the end of May and June 1. This operation adheres to the rule curve and does not violate the operation rules.

From June 22 to July 31: The amount of discharge (hydroelectric discharge) was increased to the daily amount of approximately 5 million cubic meters. The reservoir level increased gradually to a point slightly below the middle of the upper and lower rule curves.

Here, some criticism has been raised that the amount of discharge should have been increased at this point to preserve more storage capacity. Although conformity to the rule curves produced operations in line with the management rules, if the condition in October was already more or less predictable in the first half of the rainy season, then the authorities might somehow be responsible for failing to take measures to secure free space from the first half of the rainy season. In Japan, there is a precedent in flood damage litigation that ruled “it is not always sufficient for a dam installation administrator to adhere to operation rules in its dam management, but it is responsible for flexibly taking appropriate measures in a contingency" (lower court decision in the Osako Dam flood damage lawsuit) (Uga 1988). This case might serve as a reference despite significant differences from Thailand in the legal system and social background.

In the 2011 case of the Phumiphon Dam, “extraordinary inflow in the first half of the rainy season” is often pointed out as the basis of predictability. The flow at the P.12 observation point during May–June 2011, which might be regarded as de facto reservoir inflow, was the largest flow in recorded history (since 1956) for that period. This observation was claimed as a harbinger of the subsequent large inflow. Before 2011, however, no correlation had been observed between the inflow in the first half and that in the latter half of the rainy season (August–October) of any year (coefficient of determination, R^2=0.13). In other words, the substantial inflow of the first half of the rainy season could not be justified statistically as a factor indicating a large inflow for the latter half. In addition, all the three-month weather forecasts announced by Thai Meteorological Department at the end of every month during April–July indicated that precipitation in the upcoming three months would be of average level or slightly lower than average. In conclusion, based on the experience up to 2011 and meteorological and hydrological forecasting technology available at the time, no sufficient grounds, at the point before the latter half of July, existed to predict the continuance of large inflow during the latter half of the rainy season.

Through August to September 2: Typhoon Nock-ten (weakened to tropical cyclone on July 31) caused large inflow at the beginning of August. The peak flow was reduced, resulting in a somewhat rapid increase in the amount of water stored. Subsequent monsoon heavy rains caused continuous inflow exceeding the daily amount of 60 million cubic meters. The hydroelectric discharge was increased thereafter to the daily amount of approximately 30 million cubic meters to control the increase in the amount of storage. In past flood years such as 2002 and 2006, the amount of hydroelectric discharge exceeded the daily amount of 30 million cubic meters only either when the amount of water stored exceeded the upper rule curve or when the free space was reduced to less than 500 million cubic meters. In conditions in which the amount of storage is near the middle of the upper and lower rule curves, capacity of more than four billion cubic meters remains, and the amount of hydroelectric discharge during the flood season increasing to the daily amount of 30 million cubic meters is an exceptional case. The government committee in charge of dam operations was evidently beginning to show concern about the increasing inflow.

From September 28 through October 3: three tropical storms that approached or landed on the Indochina Peninsula brought heavy rains in many parts of Thailand. They rapidly increased the amount of flow into the Phumiphon Dam. The amount of discharge was raised after September 30, but the rate was, however, still slightly below 40% of the inflow considering effects on downstream areas even when the reservoir level reached 258 meters on October 3.

October 4: The inflow that had been increasing since September 28 reached a peak, and the amount of discharge reached the daily capacity of hydroelectric discharge i.e., 60 million cubic meters. This constituted only 21% of the inflow. The dam operators at this point requested the committee to grant permission for discharge from the spillways. The response of the committee, however, ordered the operators to wait (according to the testimony of the dam operators).

From October 5 to the end of October: The water level exceeded 259.50 meters on October 5. The rule was that when the water level exceeded 259.50 meters and more inflow was expected, the operation would shift to discharge of 100% of the water.

Discharge from the spillways began on the same day and continued in two periods between October 5–13 and between October 18–20, constituting a total of 12 days. The discharge used all four spillways, and the radial sluice gate was opened up to 80 centimeters from the bottom of the gate. The reservoir level exceeded its upper limit through December 13, even after the spillway discharge, because the amount of discharge was not increased in consideration of downstream areas where flooding continued. The crisis continued practically until October 31, when the daily amount of 30 million cubic meters for hydroelectric discharge resumed.

The amount of discharge during this period reached a high peak between early October and mid-October. This peak coincided with the flood that had been approaching Bangkok, which triggered strong criticism against the Phumiphon Dam operations. The relation between the amounts of inflow and discharge reveals clearly the fact that the Phumiphon Dam did not neglect the downstream area. Moreover, it discharged water with no malicious intent. Figure 2 shows that the discharge remained considerably below the inflow even after the spillways were opened and continued to function as flood control. The peak discharge on October 5 was considerably below the peak of flood inflow on October 4. The discharge of 100% of inflow (equal amounts of inflow and discharge) as specified in the rules was implemented after October 8 when the flood inflow was beginning to end. This might be viewed as a discharge operation after flood control rather than “proviso operation.” The Phumiphon Dam continued its maximum flood control using its massive storage capacity even when the reservoir was nearly full and close to its limit.

SECTION 2: Revision of operation rules and dam operations in 2012

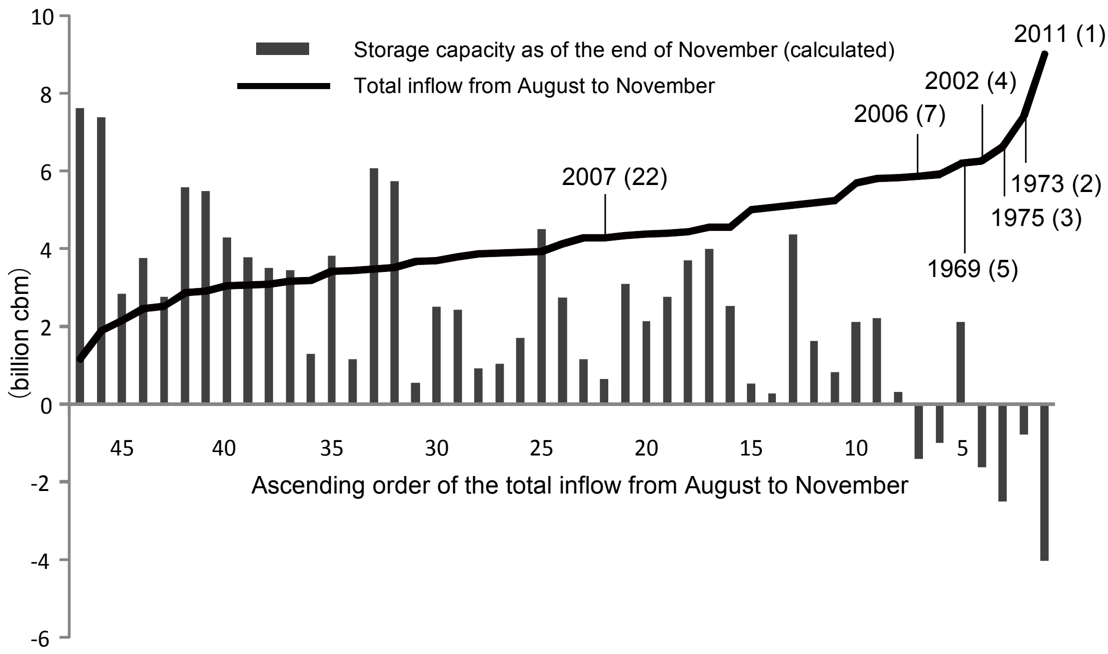
1. Flood control based on the former operation rules

On February 3, 2012, a proposal for revision of the operation rules of 33 large dams in Thailand including the Phumiphon Dam was approved by the Strategic Committee for Water Resource Management (SCWRM). This was proposed by the Thai government's working group as a flood prevention measure after the 2011 flood.

The Phumiphon Dam uses two operations to control or mitigate flooding, which are to reduce the peak flow in short-term floods and reduce the peak in the seasonal cycle. The short-term floods result from individual rainfall events (tropical cyclones, typhoons, and other heavy rains) and more frequently occur in tributaries than in the mainstream of the Chaophraya River. The peak of such short-term floods and the effect of reducing them at the Phumiphon Dam are clearly presented in Figure 2. The figure reveals that, except in early October when the spillways were opened, the amounts of discharge only slightly reflect the sharp peaks in the time-series changes in the inflow. This operation is effective for preventing flooding, particularly in the area directly downstream of the dam. Although reducing such short-term peaks is similar to flood control measures taken at dams in Japan, a striking difference is that only amounts below the inflow are discharged even after individual short-term floods (water stored through the flood control is not released). This might be caused by the huge size of the reservoir, which contributes to control of the following seasonal rise of the downstream water level. The mainstream of the Chaophraya River in and downstream of Nakhon Sawan Province is affected more by the seasonal, long-term rising of the water level that peaks around

October at the end of rainy season than by short-term rising caused by individual rainfall events. This long-term, seasonal swelling is the proximate cause of damage in the Chaophraya Delta in the 2011 flood. Such a seasonal rise of the downstream water level is a combination of inflow from tributaries, which cannot be controlled completely by the Phumiphon Dam alone. Flooding might be reduced to some extent, however, if the Phumiphon Dam and Sirikit Dam respectively control outflows from the Ping River and Nan River.

The conventional settings of the lower rule curve did not specifically examine reduction of the seasonal rise of the downstream water level, which is evident from the relations among the amounts of inflow and discharge at the Phumiphon Dam during the rainy season and the amount of water stored as of August 1. The line graph in Figure 3 presents the total flow into the Phumiphon Dam for the four months of August–November in ascending order. The bar graph presents the results of subtracting the above four-month total inflow from the remaining storage capacity as of August 1, which reveals the remaining storage capacity as of the end of November if the water were stored for the four months with no discharge at all.



(Source) Created by the author based on Hydro and Agro Informatics Institute (http://www.thaiwater.net/web/) and Chaleeraktrakun [2005]

Figure 3: total flow into the Phumiphon Dam for the four months of August–November the remaining storage capacity as of the end of November

If the storage capacity remaining at the end of November is a positive value, then the complete storage without discharge throughout the four months would be possible and the dam could use maximum control of the seasonal increase in the downstream water. Conversely, if the remaining capacity is a negative value, then at least the amount of the negative portion would have to be discharged to the downstream area. The larger the negative portion becomes, the less control the dam would have on the seasonal water rise.

This figure shows that the more water must be reduced from the downstream seasonal rise in the flood years such as 2011, the greater the negative portion of the remaining storage capacity, indicating lessening control the Phumiphon Dam over the seasonal water rise. This does not mean that the Phumiphon Dam lacks effective storage capacity, but it is a management issue of how much of the effective storage capacity should be allocated to control of the seasonal increase in the water level. The reason is that, in 1969 and 1973, when the reservoir level in August was substantially below the lower rule curve (settings as of 2011), the remaining storage capacity was either considerably positive or slightly negative despite the fifth and second largest inflows, respectively, since the construction of the dam. In major flood years in the past, including 1975, 2002, 2006, and 2011, the reservoir level as of August 1 was in the middle of the upper and lower rule curves, which demonstrated conformity to the management rules.

Additionally in 2007, when the remaining storage capacity at the end of November was small, the reservoir level as of August 1 was positioned slightly above the midpoint between the upper and lower rule curves. If a large inflow like that in the above three years occurred also in 2007, discharge operations just like in those years would have been implemented. Moreover, settings of the upper rule curve until 2011 were not intended to control short-term floods in the latter half of the rainy season. Whereas the upper rule curve approached the upper limit of water storage (full water level) from October through November in the years up to 2011, the possibility of a large flood was markedly high during this period. In all of 1975, 2002, 2006, and 2011 in which the dam reservoir level reached the upper rule curve, large short-term floods occurred between the end of September and November. Then, proviso operation or a similar operation was implemented to increase the amount of discharge substantially.

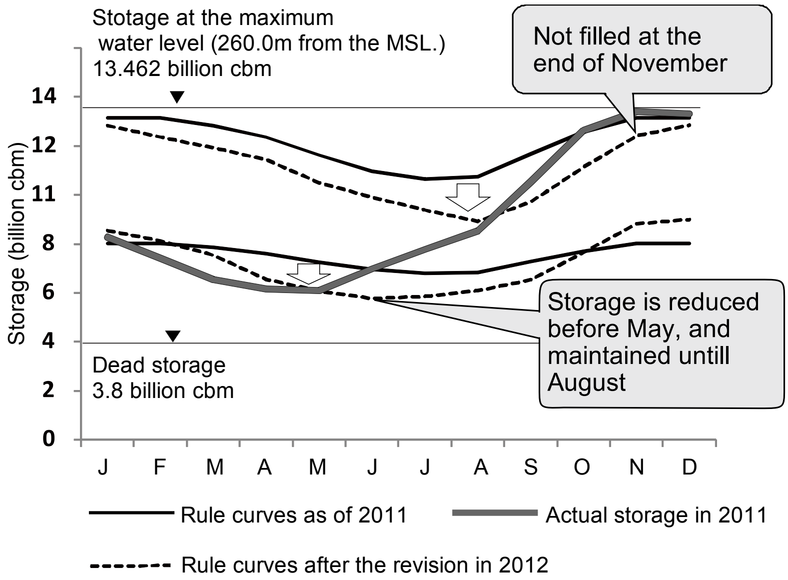
The conventional lower rule curve therefore assumed a decline in the control over the seasonal water rise in flood years. The upper rule curve accepted a reduced flood control function at the end of the rainy season. In comparison to flood control planning in Japan, such rule curve settings seemingly neglect flood prevention. How to distribute the risk of irrigation and flood prevention, however, is a matter of social consensus on related interests. Thai society has had a history of building itself while adapting to floods. During that time, its distribution of the risks of flood and drought has differed considerably from that in Japan. In recent decades, however, new industrial parks and housing areas have been developed in conventionally flood-prone regions. Lifestyles of the growing populace have grown more vulnerable to floods. The risk of damage from floods on the economy and society has indeed been increasing. Conventional dam management guidelines appropriately reflected the probabilities of flooding as a natural phenomenon, which, however, might not have incorporated the rising social and economic risks and changes in social responses. In Japan, too, however, revision of various disaster-prevention guidelines takes place only after a major natural disaster has struck. Although the failure to detect the risk in advance suggests room for improvement, using this as a reason to hold the Thai government and related authorities responsible might be somewhat unsympathetic.

2. New operation rules

As described above, the rule curves for major dams in Thailand were revised after the 2011 flood. New rule curves have been established after re-examining the balance between demands for irrigation such as agricultural and industrial water supply and the importance of flood prevention, considering approaches from the fields of meteorology and hydrology such as river runoff and rainfall, and socioeconomic aspects (Khana thamngaan jatthamphaenkaan borihaanjatkaan khuankepnamlak lae jattham phaen borihanjatkaan nam khong prathaet prajampi 2555 [2013]). Therefore, the risk distribution of flood prevention and irrig

ation was modified in line with the locations of industrial parks and social changes. Figure 4 exhibits the rule curves used until 2011 and new rule curves and the amount of water stored in 2011 at the Phumiphon Dam.

A comparison between the new rule curves and those used until 2011 reveals overall reduction in the water storage levels. The reduction is particularly great in the lower rule curves for May and June and the upper rule curves for August and September. The reduction in the lower rule curve for May was 1,185 million cubic meters (effective storage was cut by 16%) and the decrease in the upper rule curve for August was 1,822 million cubic meters (effective storage was cut by 17%) (ibid.). The stored amount would be reduced before May and would be maintained without any addition until August. Although the upper rule curve as of October 1 was below the free space of 100 million cubic meters in the settings of the conventional rule curves, the new rule curves were 233.7 million cubic meters in October, 100 million cubic meters as of November 1, and approximately 60 million cubic meters in December when the water level would reach the highest point. The total amount of discharge in October 2011 was 1,900 million cubic meters. The free space specified by the new rule curve would exceed this amount.



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Hydro and Agro Informatics Institute (http://www.thaiwater.net/web/)
and Khana thamngaan jatthamphaenkaan borihaanjatkaan
khuankepnamlak lae jattham phaen borihanjatkaan nam khong prathaet
prajampi 2555 [2013]

Figure 4: The rule curves used until 2011 and new rule curves and the amount of water stored in 2011 at the Phumiphon Dam

When this is combined with the changes in the amount stored in 2011, the amount would not be below the lower rule curve in May and would approach the upper rule curve already in early August (Fig. 4). In other words, if the new rule curves had been applied in 2011, no additional water to the storage would have been necessary in May and the amount discharged would have been increased by August to prevent the water level from approaching too close to the upper rule curve. The amount of flow into the Phumiphon Dam between August 1 and November 30, 2011 was approximately 9,000 million cubic meters. If the water level on August 1 were maintained between the new upper and lower rule curves to secure the free space of 6,000 million cubic meters and water were added to early November to raise the level to the new upper rule curve, then the large increase in the amount of discharge in early October could have been avoided while reducing the hydroelectric discharge to approximately three billion cubic meters, or 75% of the actual amount, during the same period.

An even larger change to the dam operations was that the monthly scheduled amount of discharge during the rainy season would be determined in May (ibid.). As a result, the amount of stored water would be specified, in principle, based on the amount of scheduled discharge and the actual inflow. This specification allowed the downstream area to develop flood control plans by incorporating the amount of discharge from the Phumiphon Dam in advance.

3. Dam operation in 2012 based on the new rules

In early January 2012, even before the new rule curves were introduced, the daily amounts of approximately 60 million cubic meters, or the maximum hydroelectric discharge capacity, began to be discharged from the Phumiphon Dam. This was an effort to reduce water levels as much as possible in preparation for the subsequent rainy season, which continued until early March. This was the first time that the Phumiphon Dam conducted hydroelectric discharge during a dry season without demand by downstream areas (according to an interview with a Phumiphon Dam manager in September 2012).

In May 2012, monthly discharge schedules for June and thereafter were prepared, and storage forecasts were developed for the cases of large inflow, average inflow, and small inflow based on the scheduled amounts of discharge and amount of water stored in May (see Figure 4, Sucharit [2015]). The discharge plan for 2012 specified that the amount of discharge would be reduced in or after May and water in the range of two to three billion cubic meters per month (daily average of approximately 10 million cubic meters) would be discharged from June through December. The actual discharge generally followed this plan until August. In September and October, however, the discharge was reduced to merely one-third of the scheduled amount (daily amount of approximately one million cubic meters from mid-September to mid-October). This was likely to be a result of a rapid increase in the flow of the Chaophraya River in the downstream Nakhon Sawan Province (C.2 observation point) and other areas during this period. Although the storage sharply increased in September because of this reduced discharge, a small overall inflow led to the effective storage rate at the end of November of 48%, which is in line with the forecast in the case of small inflow.

CONCLUSION

Operation of the Phumiphon Dam in 2011 was conducted in compliance with the operation rules and was the most standard performance in light of past cases. Regarding the foreseeability of the large flow into the reservoir in the latter half the rainy season and large discharge in early October, the water level was likely not so high as to change the storage operations in the first half of the rainy season, which would be against the operation rules. The implications of floods to society and consciousness of society related to floods had changed significantly since the dam construction. The resulting gap separating the conventional operation rules and the new social situation would have to be corrected in any case. It was simply unfortunate, however, that the correction was triggered by an extreme disaster described as a once-in-a-century flood.

Whether the operation rules amended this time will remain in force without further change is not certain. Although the contribution of the agricultural sector to GDP has declined to a level that is incomparably lower than that of the industrial sector, problems related to domestic agriculture have come to represent major issues in every national election, reflecting political and social influences that remain rather strong. Continuous damage caused by drought will most likely raise pressure to demand further changes to the dam operation rules. Climate change attributable to global warming might increase the risk of drought and floods, which might make it increasingly difficult to reconcile interests in flood prevention and irrigation.

The order of water supply in the Chaophraya Delta has gone through major changes rapidly. Management of the Phumiphon Dam as the current core of such order is a virtual mirror, reflecting the reality of Thailand as a country, which must be viewed continually in years to come.

REFERENCES

<Japanese>

堀川直紀・皆川裕樹・増本隆夫２０１２．「タイ国 Chao Phraya 流域の大規模貯水池運用における乾期水田灌漑用水」『水文・水資源学会２０１２年度研究発表会要旨集』７６―７７．（Horikawa, Naoki, Hiroki Minagawa and Takao Masumoto 2012. “The Irrigation Water of the Dry Season Paddy in a Large-scale Reservoir Operation in Chao Phraya Basin, Thailand,” A Summary of Workshop on Suibunn-Suishigen Gakkai 2012, pp.76-77.）

国土交通省安全・安心が持続可能な河川管理のあり方検討委員会２００８．「第４回安全・安心が持続可能な河川管理のあり方検討委員会―資料２」（Ministry of Land, Infrastructure, Transport and Tourism 2008. “4th Committee of Safety and Security is Sustainable River management: Material No.2.（http://www.mlit.go.jp/river/ shinngikai_blog/past_shinngikai/shinngikai/shakai/kasenkanri/060328/s2.pdf）.

高谷好一１９８０．「チャオプラヤ・デルタの開拓」『東南アジア研究』１７（４）３月：６３３―６５７．（Takaya, Koichi 1980. "Development of Chaophraya Delta," Southeast Asian Studies, 17(4), March, pp.633-657.）

Tanabe, Shigeharu 1973. "A Study on Development of Canal of Chao Phraya Delta (I): From Ayutthaya Era to IV King Reign of Ratanakosin Dynasty," Southeast Asian Studies, 11(1), June, pp.14-18.

宇賀克也１９８８．「ダム水害の法律問題――大迫ダム判決（大阪地判昭和６３・７・１３）を契機として――」『ジュリスト』（９２０）１０月２３―３３．（Uga, Katsuya 1988. "Legal Issues of Dam Flood: As a Trigger Decision of Osako Dam of Osaka District Court in 13 July 1988," Jurist, 920, October, pp.23-33.）

<English and Thai>

Bureau of Reclamation [1955] *Report on Yanhee Project Thailand: Power, Irrigation, Flood control, and Navigation Volume II (of two volumes) – Appendices*, United States Department of Interior.

Chaleeraktrakun, Chawarit [2005] *kaan pramaankaan khongkhuapkhum (Rule Curves) thimosom samrap angkepnamkhuan phumiphon lae khuan shirikit* [Estimation of optimal rule curves for Bhumibhol and Sirikit Reservoir.]. n.d.

Electricity Generating Authority of Thailand(EGAT) [2010] *borihan kan rabai nam lumnam chaophraya*, October 2010.

―― [2011]"khao pracha samphan chabap phiset: kho thet ching ruang kan rabai nam khong khuan phimiphon lae khuan sirikit", (http://www.bhumiboldam.egat.com/web2555/acrobat/newswater.pdf,　Accessed on January 23).

Hydro and Agro Informatics Institute [n. d.] "bantuk hetkaan mahauthokapahai pi 2554", (http://www.thaiwater.net/current/flood54.html,　Accessed on February 7, 2013).

International Bank for Reconstruction and Development [1957] *Appraisal of the Bhumiphol(Yanhee)Multiple Purpose Project*, Report No.TO-137a, August 12, 1957, (http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2002/09/12/000178830_98101903452434/Rendered/PDF/multi0page.pdf,　Accessed on May 10, 2013)

―― [1963] *Report and recommendations of the President to the executive directors on a proposed loan to the Yanhee Electricity Authority for the Second Yanhee Project*, Report No.P-317, February 13, 1963, August 1999, RID Library..

Japan International Cooperation Agency (JICA) [1999] *The Study on Integrated Plan for Flood Mitigation in Chao Phraya River Basin: Final Report Vol.4 Supporting Report(2/2)* , August

1999, RID Library.

Kaida, Y.[1974] ”Pioneer settlement and water control development in the west bank of the lower Chao Phraya Delta,” *Tonan Ajia Kenkyu (Southeast Asian Studies)*, Vol.11, No.4, pp.512-524.

Khana thamngaan jatthamphaenkaan borihaanjatkaan khuankepnamlak lae jattham phaen borihanjatkaan nam khong prathaet prajampi 2555 [2013] “raaingaan kaan prapprung keenpathibatkaan angkepnam” , (http://ichpp.egat.co.th/graphIN/hydro/Rule_curve.pdf, Accessed on February 7, 2013).

Koontanakulvong, Sucharit [2015] “Short Term Floods Mitigation Measures after Thailand Floods 2011,” *The 2011 Thailand Floods: Lessons and Records* (http://www.ide.go.jp/English/Publish/Download/Spot/pdf/s01/004.pdf, Accessed on January 30, 2015)

Khunthanakunwong, Sucharit, and khana nuaipathibatkaan wijai rabopkaanjatkaanlaengnam khanawisawakamsaat julalongkonmahawitthayalai [2012] *sathanakan nam nai prahet thai pi 2550*, Bangkok, Thailand: khana nuaipathibatkaan wijai rabopkaanjatkaanlaengnam khanawisawakamsaat julalongkonmahawitthayalai.

Setthaputra, Sacha, Pahayotou, Theodore, and Wangwacharakul, Vute [1990]”Water shortage: Managing demand to expand supply,” *The 1990 TDRI Year-End Conference Industrializing Thailand and its Impact on the Environment*, p.97, Bangkok: Thailand Development Research Institute Foundation (TDRI).