CONCEPT PAPER

Investigation of the Potential to Reduce Flood Risks in the Chao Praya Basin
[While Improving Water Supply and Fisheries]
Through Reservoir Reoperation in Conjunction with Groundwater Banking and Floodplain Reactivation

Presented by
The Department of Water Resources of the Kingdom of Thailand
and the Natural Heritage Institute

INTRODUCTION

Global climate change is already causing the precipitation patterns in Thailand to become more extreme. Within the past 5 years, Thailand has experienced the drought of record and the flood of record. Both conditions require enhanced ability to manage and control the hydrologic extremes. This paper describes an integrated strategy for doing so by managing the already existing physical infrastructure in conjunction with the natural infrastructure, consisting of the groundwater system and historic floodplains, based on experience in California and elsewhere in the world.

After the horrific floods of 2011, improvements in flood management are the highest priority in the water resources planning arena for the Government of Thailand, which is developing a five- point strategy for the Chao Praya basin:

1. Watershed afforestation to attenuate the rate of runoff into the Chao Praya;
2. Check dams in the river to accelerate the percolation of surface waters into the groundwater system;
3. Reoperation of reservoirs to improve flood reservation;
4. Utilization of historic floodplains to provide transitory storage and attenuate flood events;
5. Conveyance facilities (a huge pipe) to conduct flood waters around Bangkok.

The Natural Heritage Institute (NHI), a non-governmental organization, several agencies of the national government of the United States, and the State of California have conducted analysis that is directly relevant to the third and fourth of these strategies: reservoir reoperation and transient floodplain storage. Some of this experience is listed in an attachment to this Concept Paper. The central theme of this work is exploring the potential for reoperation of multi-purpose reservoirs that have a flood control and irrigation water supply function in conjunction with groundwater storage and controlled inundation of historic floodplains to achieve three simultaneous objectives: (1) reduced flood risks, (2) improved water supply, and (3) restoration of more natural flow patterns downstream of these dams. This work is particularly important at this time as Thailand, the United States, and, indeed, the entire world are facing the reality of more extreme hydrologic events—both floods and droughts—as a consequence of global warming.

The Kingdom of Thailand may be interested in the learning that is coming out of this work in the United States (and similar work that NHI is about to undertake with national and local agency partners in the Yellow River in China, northern Nigeria, and the Krishna River basin in India. The Chao Praya basin possesses the same physical characteristics that have proven conducive to this water management innovation in the other basins that have been studied. The two large reservoirs in the Chao Praya basin, Bhumibol and Sirikit, are multi-purpose reservoirs that also provide irrigation water supply and hydropower generation. A strategy to reoperate these Chao Praya reservoirs in conjunction with groundwater storage and reactivated floodplains could capture a larger fraction of the peak flow events generated by the monsoon while also buffering the effects of drought periods. Both the high flows and the droughts are likely to become more pronounced in the future. Also like in the other examples cited in Attachment A, reoperation of these Chao Praya reservoirs could provide the added benefits of improving water supply and restoring the downstream environmental conditions for fisheries. Basically, this is a strategy to integrate the natural infrastructure in the river basin—the groundwater system and the floodplains—with the man-made infrastructure, the dams, levees, diversion works and conveyance systems.

THE NATURE OF THE FLOOD PROBLEM IN THE CHAO PRAYA BASIN

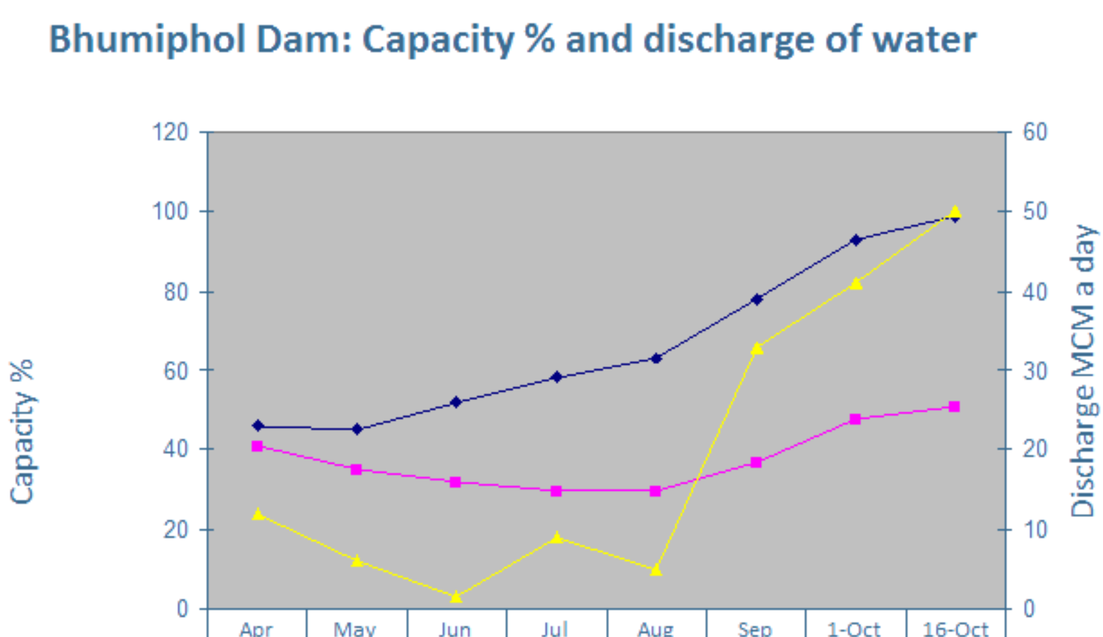
Since 1950 the Government of Thailand has constructed some 3,000 dams to store the monsoon flows for use in the dry-season to serve Thailand's vast agricultural potential and to meet the growing demands of industrial and urban users. The two largest dams constructed in the Chao Praya basin are the Bhumibol and Sirikit Dams, which supply stored water for electricity generation, irrigation, and domestic and industrial water use. Together these two dams control the runoff from 22% of the area of the entire basin. Bhumibol Dam, on the Ping tributary, has a live storage capacity of 9.7 billion cubic meters, compared to the average annual inflow of 6.6 billion cubic meters from a drainage basin of 26,400 km^2. The installed hydroelectricity generation capacity is 713 MW. The dam was completed in 1963, and filled for the first time in 1970. Sirikit Dam on the Nan tributary was completed in 1972. It has a live storage capacity of 6.0 billion cubic meters compared to the average annual inflow of 5.9 billion cubic meters. The installed hydroelectricity generation capacity is 500 MW. Both of these dams are operated by the Electricity Generating Authority of Thailand, a state-owned enterprise.

The severe flooding that occurred during the 2011 monsoon season in Thailand is a harbinger of events that will become commonplace as the world climate changes. These events will alternate with periods of extreme drought. The flooding began at the end of July, triggered by the landfall of Tropical Storm Nock-ten. Flooding soon spread through the provinces of Northern, Northeastern and Central Thailand along the Mekong and Chao Phraya river basins. In October floodwaters reached the mouth of the Chao Phraya and inundated large parts of the capital city of Bangkok. Flooding persisted in some areas until mid-January 2012, affecting 13.6 million people and resulting in over 800 deaths. 65 of Thailand's 77 provinces were declared flood disaster zones, and over 20,000 square kilometers (7,700 sq mi) of farmland was damaged.

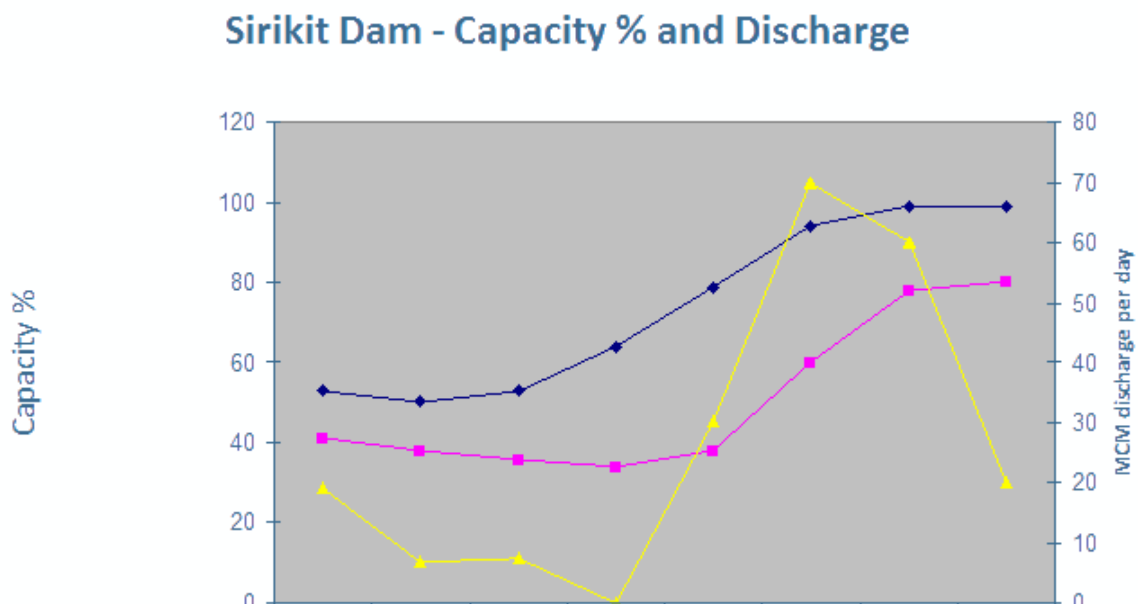
The World Bank has estimated 1,425 billion baht (US$ 45.7 billion) in economic damages and losses due to the flooding.

The size and scope of the damage from the 2011 flood can be attributed in part to the low rainfalls of the preceding monsoon season. Dam levels hit record lows in June 2010. In response, the dams collected large amounts of water early in the 2011 monsoon season to build reserves and buffer the early flooding. By the beginning of October, most dams, including 11 of the country's 26 major dams, were already near or over capacity, according to reports released by the Royal Irrigation Department, and these dams were forced to increase their rates of discharge, worsening the downstream flooding. At the largest dam in the Chao Praya basin, the Bhumibol Dam, over 8 billion cubic meters of water were collected in 3 months, filling this dam to 100% of its capacity. This was happening as 23 provinces were already flooded and a new tropical storm was expected to bring more rains. The Chao Phraya River was flowing at a rate of 4,344 cubic meters per second through Nakhon Sawan and at 3,255 cubic meters per second through Ayutthaya's Bang Sai district. Chiang Rai, Nan, Nong Khai, Beuang Kan, Sakhon Nakhon and Nakhon Phanom residents were experiencing flash floods.

As the continuing rains forced officials to increase discharges from the dams that were already at their capacity, the resulting increase in flooding led to accusations that the dams were mismanaged early in the monsoon season. However, the counter argument is that had the reservoirs been drained for flood control and then the monsoon season for 2011 been short, the reservoirs would not have refilled, resulting in even lower levels than 2010.



	Apr	May	Jun	Jul	Aug	Sep	1-Oct	16-Oct
2010 Capacity	41	35	32	30	30	37	48	51
2011 Capacity	46	45	52	58	63	78	93	99
Discharge	12	6	1.5	9	5	33	41	50



	Apr	May	Jun	Jul	Aug	Sep	1-Oct	16-Oct
2010 Capacity	41	38	36	34	38	60	78	80
2011 Capacity	53	50	53	64	79	94	99	99
Discharge	19.07	6.98	7.5	-	30.13	70	60	20.01

NOTE: Capacity % refers to the dam capacity; MCM refers to million cubic meters released per day. All figures are calculated as of the first of each month only. For the full month's discharge on an **accumulated** basis:

THE PHYSICAL SOLUTIONS UTILIZING RESERVOIR REOPERATION IN CONJUNCTION WITH "NATURAL INFRASTRUCTURE"

The challenge for water managers in Thailand, facing more extreme and frequent floods intermixed with extended drought is to store and control a greater fraction of the peak rainfall events, when they occur, for use when they do not. That will reduce flood risks and increase water supply reliability. That is conventional water engineering. Yet the conventional engineering solution—building more storage dams and levees—is no longer viable in Thailand and many other developed countries. The best sites for flood control dams have already been exploited and the political tolerance for the environmental costs of such infrastructure is at its limit.

This paper describes an alternative for increasing the effective storage of flood waters without exacting an environmental penalty. Indeed, this is a strategy that can substantially reverse the past adverse environmental impacts of Thailand's dams. This can be done by re-operating the existing storage dams in conjunction with the groundwater system and the historic floodplains – the "natural infrastructure" in the system. At noted in Attachment A, these are techniques that now being explored also in the Central Valley of California, in West Africa, in China, and other settings around the world.

Improving Flood Management

This strategy is actually rather obvious. Flood management is problematic because of two factors: (1) insufficient storage capacity in the existing dams to contain and attenuate flood events, and (2) constraints on the rate at which water can be released without damage to floodplain development. Therefore, the best response is to increase both the storage capacity and the ability of the downstream floodplain to accommodate controlled high flow events. The flood storage can be effectively increased by moving water from the reservoir to the groundwater system before the onset of the monsoon season. Carried to its ultimate extreme, these flood control reservoirs would be lowered to dead storage every year through this technique. Then, if the monsoon delivers relatively little refill—drought conditions—the water in storage in the ground that can be recovered to make up for the deficit in the reservoirs.

At the same time, flood retention can be increased by utilizing carefully selected portions of the historic floodplain and bypass channels to temporarily store, attenuate and route the flood waters, while maintaining physical barriers to the high waters in portions of the floodplain where such modifications are not practical. This allows the reservoir to release water at a greater rate in anticipation of a large storm event, which increases the effective flood control capacity of the reservoir. However, reconnecting the river to its floodplain in this manner may require that some structures on the river bank be relocated and that some land uses be modified to accommodate larger controlled flood events during a portion of the monsoon season. The lands that are temporarily inundated will also benefit from the replenishment of nutrients and soil moisture. Farmlands cultivated with seasonal crops (e.g. rice) are good examples. Structures that cannot be easily relocated are examples of land uses that must continue to be protected from the river.

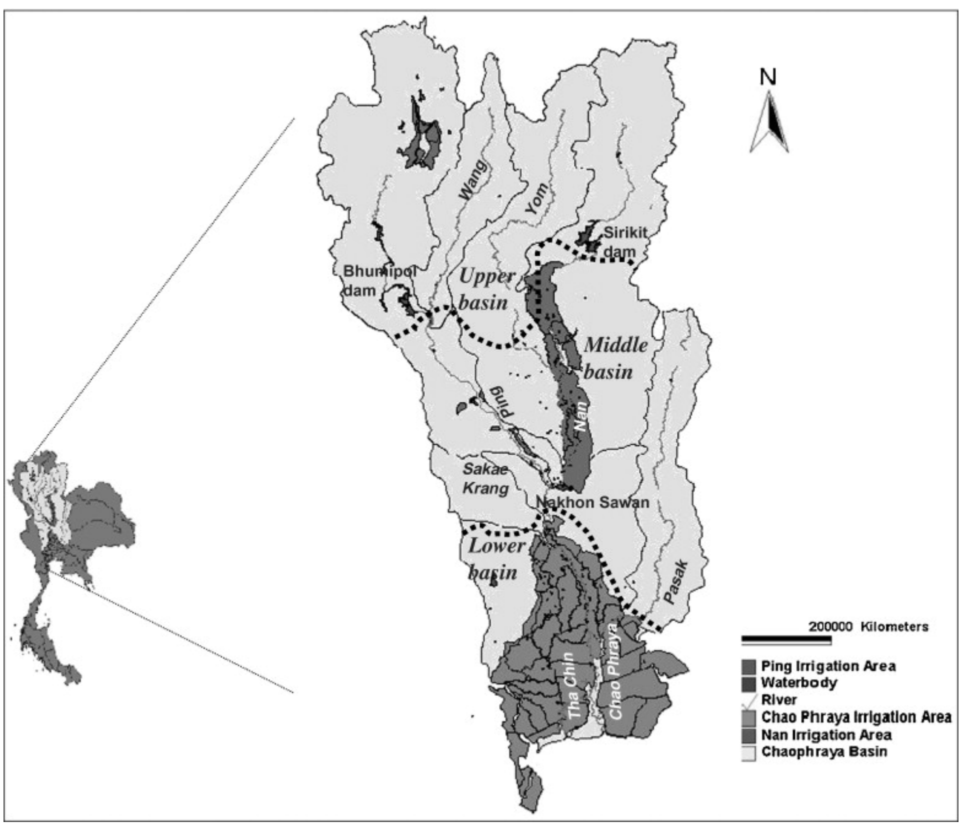
Restoring Aquatic Ecosystems and Fisheries

Re-connecting the river to its floodplain on a seasonal basis through re-introduction of controlled inundation patterns can also provide major improvements in the environmental productivity of the river system. It is the interaction of the river with its landscape that is the great engine of biological productivity, which results in improved fisheries and aquatic biodiversity. Even if the floodplain development cannot be modified substantially, reservoir reoperation in conjunction with groundwater banking can enable more environmentally productive flow patterns to be released from the reservoirs for two reasons. The first reason is that this technique generates additional water supply that can be dedicated in part to enhanced environmental flows; often that water can then be diverted for irrigation or municipal uses at a location downstream of the reach where fishery restoration is desired. The second reason is that banking water in the ground provides more flexibility in reservoir storage and release patterns. For instance, at times when it would be beneficial to reduce diversions from the river to protect environmental flows, irrigation water can be provided from the banked groundwater instead.

Therefore, developing an environmental restoration plan is one of the key challenges in designing a reoperation program. The objective is to restore the river flows and floodplain, to the extent practical, to the conditions that existed before the dam was built. In the Chao Praya, that means re-creating conditions that will bring back the original swamp forests inland and salty mangroves on the coast and the estuary. These have been almost entirely lost as the floodplain has been converted to rice paddies, other agriculture, and urban areas. As a consequence, much of the wildlife that once inhabited these plains has disappeared including a large number of fish in the river systems, birds such as vultures, the Oriental Darter, White-eyed River Martin (Pseudochelidon sirintarae) and the Sarus Crane and animals such as the much-hunted Schomburgk's Deer.

<u>Illustrating These Techniques in the Chao Praya Basin</u>

To illustrate how these techniques can work, let us focus on the Chao Praya basin and its two large, multi-purpose storage dams, Bhumibol and Sirikit. The headwaters of the Chao Phraya River originate in mountainous terrain in the northern part of the country and consist of four large tributaries, the Ping, Wang, Yom and Nan rivers. The main river system passes through or close to many of the major population centers of the country including the capital, Bangkok, which is situated at its downstream end. The flows in the Chao Phraya and its tributaries are dependent on the monsoon rains during May to October and are highly variable. Average annual precipitation in the Chao Phraya basin varies from a minimum of 1,000 mm in the western part to about 1,400 mm in the headwaters and up to 2,000 mm in the eastern Chao Praya delta. Variations from year to year, which are responsible for floods and droughts, are key factors in determining the availability of the basin's water resources. About 85% of the total runoff occurs in the months of July to December, and natural flows are small in the January to June period. Average annual runoff recorded in the upper Chao Phraya basin varies from about 250 mm in the sub-basin of the Ping above Bhumibol reservoir to some 450 mm in the sub-basin of the Nan above Sirikit reservoir.



As the chart below shows, the Bhumibol and Sirikit, capture the runoff in the Ping and Nan sub-catchments respectively, which are much the largest in the basin. Likewise, these dams are by far the two largest in the Chao Phraya River basin. Together they control the runoff from 22 percent of the entire basin. These dams are operated for flood control as well as water supply and hydropower.

Sub-basin	Catchment Area(km^2)	Total Volume(m^3)
Ping	35,535	9,073
Wang	11,084	1,624

Yom	19,516	3,684
Nan	32,854	11,936
Sakae Krang	5,020	1,096
Pasak	15,647	2,823
Tha Chin	18,105	2,449
Chao Phraya main stream	21,521	4,435
Chao Phraya basin	159,283	37,120

The following table lists the major dams in the Chao Phraya Basin:

Reservoir name	Sub-basin	Max retention (Mm^3)	Normal retention (Mm^3)	Min retention (Mm^3)	Effective storage (Mm^3)	Irrigation Area (ha)
Bhumibo	Ping	13,456	13,462	3,800	9,600	1,200,000 ha in the wet season and 480,000 ha in the dry season
Sirikit	Nan	10,640	9,510	2,850	6,660	
Kiew Lom (=Kiu Lom)	Wang	112	112	4	108	8,800
Mae Ngat	Ping	325	265	10	255	30,080
Mae Kuang	Ping	263	263	14	249	28,000
Mae Chang	Wang	108	N/A	N/A	N/A	N/A
Thap Salao	Sakae Kang	198	160	8	152	10,400
Kra Sieo	Tha Chin	363	240	40	201	N/A
Pa Sak	Pa Sak	960	N/A	N/A	785	N/A

Now let us look at how these dams could be re-operated to provide multiple benefits, starting with their irrigation operations. These irrigation schemes are the largest in the country, providing irrigation water for 1,200,000 hectares in the wet season and 480,000 hectares in the dry season. These dams were initially constructed to provide supplementary irrigation in the lower Chao Praya basin during the wet season, but progressively have been required to provide ever increasing amounts of irrigation water for the dry season. The dry season irrigation is of greatest interest for our purposes.

The re-operation strategy involves connecting this irrigation system with is underlying groundwater system. Hydrogeologically, the Chao Phraya river Basin comprises seven groundwater sub-basins; namely; Chiangmai-Lampoon Basin, Lampang Basin, Payao Basin, Prae Basin, Nan Basin, Upper Chao Phraya basin, and Lower Chao Phraya basin. The latter two are by far the largest, and of greatest interest for the reoperation strategy. Groundwater storage and safe yield within these sub-basins has been estimated as shown in the table below.

Groundwater storage and safe yield of the Chao Phraya river sub-basins *

Groundwater Basin	Groundwater Storage (million m^3)	Safe Yield per year(million m^3)	Safe Yield per day(m^3)
Chiangmai-Lampoon	485	97	265,000
Lampang	295	59	161,000
Chiangrai-Payao	212	42	115,000
Prae	160	32	87,000
Nan	200	40	110,000
Upper Chao Phraya	6,400	1,280	3,500,000
Lower Chao Phraya	6,470	1,294	3,500,000
Total	**14,222**	**2,844**	**7,738,000**

* The calculation is based on the assumption that amount of groundwater storage is depend on the change of water level, area of aquifer, and storage which is varies to geology of each area, such as unconfined, confined, or semi-confined.

The use of groundwater for agriculture is mainly to supplement surface water supplies. Groundwater consumption is more acute during the dry season and in drought years for land preparation, crop needs in the early part of the wet season, and as supplementary source of water for farms located at the tail-end of distribution canals. Therefore, a flood management strategy that replenishes groundwater and raises the groundwater levels will also have major benefits for agricultural water supply. The basin faces a growing problem in the management of groundwater resources. As noted, the irrigation system was originally intended to provide supplementary irrigation for the wet season. It is only recently that it has also been required to provide dry season irrigation, when it has to compete with demand from other sectors. [1] This has become a sensitive issue as the available water resources can no longer meet the increasing water demand from all sectors. This water competition has led to poor agricultural performance in recent dry seasons.

THE REOPERATION SCENARIO

The concept that we propose to assess would operate essentially as follows:

- Toward the end of the dry season irrigation season, the farmers in the irrigation command area served by Bhumibol and Sirikit Dams would be required to turn off their wells and

[1] Groundwater is an important source of water supply in Thailand. Public water supplies for 1/5 of the nation's 220 towns and cities and for half of the 700 Sanitary Districts are derived from groundwater. It is estimated that 75 per cent of domestic water is obtained from groundwater sources. More than 200,000 groundwater well projects were undertaken by both government and private parties with total capacity of about 7.55 million cubic meters per day. (2,700 million cubic meters per year).

take reservoir water instead, with the goal of lowering the reservoir storage levels to dead storage.

- There are three potential circumstances for accomplishing this change:

  1) In areas where the farmers already have access to both the reservoir water and groundwater wells, the farmers would be required to switch these sources on and off as necessary to make the reoperation program work as described above.

  2) In areas where there are farmers near to, but outside of the irrigation command area, the canal system would be extended to them so that they can take reservoir water instead of pumping the groundwater. They would then be required to switch these sources on and off as necessary to make the reoperation program work as described above.

  3) In areas within the existing command area where the farmers have access to reservoir water only, groundwater wells would be drilled to give them access to both resources. They would then be required to switch these sources on and off as necessary to make the reoperation program work as described above.

- The lowered storage levels in the reservoirs would increase their capacity to capture the peak flood events, releasing them slowly into the downstream channel. This would substantially reduce downstream flood risks.

- In the event that the monsoon rains are inadequate to fill the reservoir to the level that would have otherwise occurred, the deficit would be made up by requiring farmers who would ordinarily take reservoir water to pump groundwater instead.

- Because the reoperation of the reservoir captures a larger portion of the flood waters (water that would otherwise have to be discharged, there will be a net increase in water supply. That additional water can be used for two purposes:

  1) To increase the water supply available for dry year irrigation or municipal water supply. In some cases, the best option may be to use it to replenish the groundwater table so that the pumping costs for all users will go down.

  2) To increase the releases from the dam during the monsoon season to create seasonal floodplain inundation to improve the productivity of the river fishery. This may require modifying the land uses in the floodplain, as described above. Ideally, the larger flows during the monsoon season will be compensated by lower releases during the dry season to emulate the natural variability in flow patterns that existed before the dams were built.

- At the same time that the dams are being re-operated to better control the flow pattern, the downstream floodplains will be reconnected to the river to enable controlled flooding to store flood waters while also improving the conditions for fish production. As noted above, this is accomplished by strategically modifying the floodplain land uses to accommodate larger seasonal flows. In the farming areas along the Ping and Nam rivers, cultivation practices would be modified to allow the farmlands to be temporarily inundated during a few weeks of the peak monsoon period, providing valuable moisture and nutrients. This may involve some conversion from orchards to seasonal crops. Some compensation to these farmers may be necessary. In some areas, relocating structures to sites higher in the floodplain may be needed. In other places, reactivation of historic flood by-passes may be used. In other places, where controlled inundations are not practical, the existing levee system may need to be maintained or strengthened. The best plan for floodplain reactivation will require a survey of the downstream development conditions.

This reoperation concept will provide at least three large benefits:

1) More water will be in storage to buffer the effects of extended droughts. This is accomplished by using the groundwater system in addition to, and in conjunction with, the reservoirs. An additional benefit will be replenished groundwater tables which will reduce the pumping costs for all groundwater user;

2) Much reduced risks of damage from floods for two reasons: (1) more flood storage capacity in the reservoirs, and (2) less vulnerability to structures and farmlands due to the floodplain modifications;

3) Improved productivity of the river fisheries because of much better conditions for reproduction, rearing and growth.

There are also likely to be three other benefits:

(i) Increased hydropower output: the hydraulic head in the reservoir can be maintained at a higher level without creating flood risks because the reservoir can discharge at a higher rate due to the downstream flood proofing, and

(ii) Greater resilience to climate change.

A reoperation program of this nature is complex and fraught with uncertainties. Therefore, it is best implemented incrementally, starting with a pilot-scale application of the techniques to demonstrate the measures and test the assumptions. The results are then monitored and adjustments are made to achieve better results over time. However, to determine how and where to conduct a pilot study for best results, and to determine the elements and techniques to include in the test case, it is necessary to first create a simulation of the entire Chao Praya water system to assess various alternative configurations of a reoperation scheme. A system-wide initial analysis is essential because it is important to understand how changes to any part of the system will affect all the other elements. That approach will illuminate the optimal design and make clear how to combine the various elements into a successful pilot demonstration project while avoiding costly mistakes. This is how this analysis has been carried out in the examples in Attachment A. It is also the most efficient and expeditious way to proceed. Therefore, the study plan outlined below starts with a system-wide simulation and progresses to a pilot implementation phase.

TASKS TO INVESTIGATE THE FEASIBILITY AND EFFICACY OF THE REOPERATION CONCEPT

Task 1: Collect the additional information needed to create a whole-system planning model. Items include:

- Current operating rules/policies for Bhumibol and Sirikit dams.
- Hydrologic records over a substantial period of record
- Groundwater use patterns within and adjacent to the irrigation command areas
- Geohydrologic information in the aquifers underlying the command areas
- Irrigation operations in the command area
- Floodplain geometries and floodplain development constraints

Task 2: Estimate environmental restoration flow targets to rehabilitate the fishery resources that are most valuable for human food security and biodiversity

Task 3: Create a model to simulate all of the relevant physical processes (hydrology, fluvial geomorphology, groundwater dynamics, etc.)

Task 4: Generate the reoperation scenarios that appear promising for the multiple objectives described in the concept paper.

Task 5: Utilize the planning model(s) to evaluate the scenarios iteratively, refining and optimizing with each iteration.

Task 6: For the scenarios that perform best, conduct an economic feasibility analysis.

Task 7: For the scenarios that prove to be economically feasible, develop an implementation plan that is legally and institutionally feasible.

Task 8: Develop a reoperations plan that combines the best performing scenario(s).

Task 9. Select a pilot scale demonstration that tests the approach that the modeling indicates will perform best and implement it on a trial basis

Task 9: Monitor the results of the trial implementation and adjust the reoperation plan accordingly

Task 10: Develop and implement a permanent reoperation program at the basin scale.

FORMING A PARTNERSHIP TO UNDERTAKE THE STUDY

The core of the project team must consist of the cognizant agencies of the government of Thailand, supplemented by the governmental agencies and non-governmental organizations (NHI) with the requisite experience and expertise to complement the capabilities of the Thai partners. The lead partner for the Kingdom of Thailand will be the Ministry of Natural Resources and Environment (MoNRE) and its sub-agencies including the Department of Water Resources, Royal Irrigation Department and Department of Groundwater Resources. It is also important that the Electricity Generating Authority of Thailand be brought into the project because the large flood control reservoirs are owned and operated by EGAT for hydropower. And the local groundwater management authorities may also be indispensable.

The foreign partners would consist of the Natural Heritage Institute, which has done pioneering work on the reoperation concept and has an experienced technical team. NHI can manage the project, if desired.

For further information, please contact:

Dr. Sukontha Aekaraj
Director of Foreign Affairs
Thai Department of Water Resources
Ministry of Natural Resources and Environment
saekaraj@hotmai.com

Gregory A. Thomas
CEO
Natural Heritage Institute
100 Pine Street, Suite 1550
San Francisco CA 94111
Office: (415) 693-3000 Ext. 101
Cell: (415) 513-3362
gat@n-h-i.org