Chao Phraya Delta:
Paddy Field Irrigation Area in Tidal Deposit

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Abstract

Due to the recent interest of International Commission on Irrigation and Drainage (ICID) on Sustainable Development in Tidal Areas (SDTA) but no report on this subject from Thailand has been included, motivated the author to contribute to this article entitled Chao Pharya Delta which is the recommendation of Food and Agriculture Organization (FAO) in 1948 that Thailand's economic strength lay in exporting high yielding rice 2-3 times/year to alleviate world-wide food shortages caused by the war. In 1950, Thailand secured a World Bank loan, and in 1952 commenced work on a 25 year irrigation enhancement program. Work began in 1953, and at its completion in 1957, the Greater Chao Phraya Project was considered Asia's largest irrigation project. In 1961 additional components, such as Bhumibol dam and irrigation canal system were constructed and became operational in 1964. The construction of Sirikit dam was finally finished in 1977.

The Greater Chao Phraya and the Mae Klong irrigation projects, located in the Asian monsoon region with heavy rainfall and high tides at the head of the Upper Gulf of Thailand which provide effective silt-deposits due to strong tidal action is the most fertile areas for rice production located in the upper part of freshwater zone of the delta. Fruit orchard is in the middle part of blackish water while aquaculture is in the lower part of saltwater zone.

This paper summaries development of irrigation projects by Royal Irrigation Department in the Chao Phraya delta, its sustainable development on drainage and flood mitigation. Interaction of tides and river flow is clearly illustrated by means of analytical models based on harmonic analysis and perturbation method.

Introduction

1. Chao Phraya Delta

The Chao Phraya delta is at the southern part of the Chao Phraya basin as shown in Figure 1 which has a catchment area of 162,000 km^2 shown in Figure 2a while the Mae Klong basin is on the west as shown in Figure 3. Based on geographic setting, topography and flow conditions, the Chao Phrya basin has been divided into regions and sub-regions as follows.

a) The Upper basin has two parts, the mountainous area and the central plains upstream from Nakhon Sawan. The valleys are long and narrow, with steep densely vegetated slopes. In places the valleys widen into alluvial flood plains and settlements such as in Chiang Mai, Lampang, Phrae and Nan on the Ping, Wang, Yom and Nan rivers respectively. The catchment of the Ping is the most mountainous, rising to a height of 2,576 m MSL, and the longest with a river length over 600 km. The limit of the mountainous area is marked by the confluence of the Ping and the Wang at Tak at a level of approximately 100 m MSL and 570 km from the Gulf of Thailand, close to Phrae on the Yom and Uttaradit on the Nan at an elevation of 100 m MSL and 740 km from the gulf, and Amphone Pattananikom on the Pasak at an elevation of 25 m MSL and 300 km from the gulf (see Figures 2a and 2b)

The Upper central plains lie below the mountainous region and above the confluences near Nakhon Sawan on the Chao Phraya, and above Saraburi on the Pasak. The plains comprise sedimentary deposits, with isolated limestone outcrops. The Yom and the Nan are less steep and are embanked below Phitsanulok, protecting irrigation project areas from flooding.

b) The Lower Chao Phraya basin, downstream from the confluence of the Ping, Yom and Nan, commences at Nakhon Sawan. The basin covers an area of 37,300 km^2 and is mainly an alluvial plain formed by the river system. Nakhon Sawan is at an elevation of 25 m MSL, 360 km from the Gulf of Thailand (see Figures 2a and 2b)

The river system has elements of a delta commencing at Chainat, 70 km south of Nakhon Sawan, where the main Chao Phraya branches in the Suphan and Noi Rivers, and further downstream into the Lopburi River. The Suphan River continues as the Tha Chin and discharges directly to the Gulf of Thailand, while the other channels rejoin the main Chao Phraya near Bangsai, 110 km north of the mouth at the Gulf of Thailand. The rivers are embanked protecting the vast irrigation project areas from flooding. Numerous artificial

channels interconnect the natural rivers, initially used mainly for transport, and now mainly for irrigation. The reach is referred to as the Upper delta.

The Lower delta reach downstream of Bangsai is influenced by the tide in the flood season. The City of Bangkok lies on both banks of the river, with the urban area extending from the river mouth to Pakkret, some 70 km upstream; the urban area covers around 535 km^2. The city and the surrounding area have a dense network of canals which drain the area; the general land level is around one meter above mean sea level and pumping is necessary as the land has settled by as much as up to 1.5 m in some areas, largely owing to ground water abstraction.

2. The Mae Klong Basin

The Mae Klong basin as shown in Figure 3 is on the west of the Chao Phraya basin as shown in Figure 1. The characteristics of the basin are as follows:

a) The total area of the river basin is about 31,000 km^2, of which about 15,000 km^2 and 11,000 km^2 are catchment areas of the Khwae Yai and Khwae Noi rivers respectively. Forest land, agricultural land and water body presently occupy 73% , 19% and 3% of the whole river basin respectively.

b) Administratively, the river basin is divided into 25 districts of 8 provinces, though about 70% of the basin area belongs to Kanchanaburi, Ratchaburi and Samut Songkhram provinces.

3. The Greater Chao Phraya Project

The Chao Phraya project began in 1953, and at its completion in 1957, it was considered Asia's largest irrigation project. The dam, renamed the Chao Phya Dam, stretched 237.5 m across the river and was fitted with 16 sluice gates, each 12.5 m wide. Its maximum high-water discharge was 3,300 m^3/s. (Van Beek, 1995).

RID in 1957 reviewed the 117 years since the stone gauge at Ayutthaya had been erected. It noted that in 4 years unusually high floods had damaged crops. Conversely, in 60 years the lower valley had suffered drought, with 21 years of moderate drought, 35 years of severe drought, and 4 years of extreme drought, a total of 51 percent of the entire period, by no means a small percentage. It further noted that high-yielding 180-day rice required 1,800 mm of water to produce a bountiful harvest (excluding an extra 800 mm to compensate for evaporation and canal leaks) and that normal rainfall was in-sufficient to provide it. It

concluded: it is clear therefore that without irrigation, the central plains, the rice bowl of Thailand cannot be made to produce the maximum yield it is capable of producing for the benefit of the rice-eating peoples of the world.

To extend irrigation to the extremities of the basin, trunk canals were dug along the far edges of the valley. On the east, the Chainat-Pasak Canal was excavated from the Chao Phya Dam to Rama VI Dam on the Pasak River (see Figure 4). On the west, the Makham Tao-U-Thong Canal was excavated south-wards from the dam to a point near U-Thong. The area between the eastern and western borders of the project would be served by the Tha Chin River, the Chao Phraya and Noi and by a specially constructed trunk canal which ran from Chainat to Ayutthaya along the high left bank of the Chao Phraya. The height of the latter enabled it to feed the adjacent fields and distribution channels by gravity, even when the dry-season river-levels were low. During the rainy season, the five channels would also help draw flood waters away from the river, spreading them across the valley, thereby reducing the river's destructive force. This phase of the project became operational in 1962.

In 1961, the Government approved the construction of a large scale dam across the Nan River, a tributary of the Chao Phraya River at Phasom Sub-district, Tha Pla District, Uttaradit Province. This dam was under taken to be a multipurpose project as the Bhumibol Dam due to its appropriate location. The project was also funded by a World Bank loan. The construction was finished in 1977 and was graciously named by H.M. the King "Sirikit Dam". The dam provides benefits of electricity generation and water drainage to the Greater Chao Phraya Project and its merging with water releasing from the Bhumibol Dam also provides water for cultivation in the Chao Phraya basin (RID, 2002)

The irrigation project areas of the Tha Chin river are listed in Table 1, those of the Mae Klong river are listed in Table 2 and those of the Chao Phraya river are listed in Table 3 which are shown in Figures 5 while schematic diagram of the Chao Phraya river and its tributaries are shown in Figure 6. This irrigation area of 13 million rai is the largest oneof Asia and Thailand is ranked first as rice exporting country of the world.

Table 1 Large Irrigation Projects in the Tha Chin River.

Project Name	Command Area (Rai)	Irrigation Area (Rai)	Project Year	
			Begin	Finish
Pholathep	103,000	96,000	2495	2506
Tha Bote	218,356	196,356	2495	2506
Sam Chuk	372,100	305,000	2478	2498
Pho Phraya	415,940	370,000	2464	2476
Krasieo	124,151	111,736	2509	2525
Sum of Upper Part	1,233,547	1,079,092		
Chao Chet-Bang Yihon	437,850	406,000	2482	2493
Phraya Banlu	485,530	358,650	2482	2493
Phra Pimon	293,840	266,000	2482	2493
Phasi Charoen	350,000	124,800	2448	2450
Sum of Lower Part	1,567,220	1,155,450		
Overall Sum	2,800,767	2,234,542		

Table 2 Large Irrigation Projects in the Mae Klong River.

Project Name	Command Area (Rai)	Irrigation Area (Rai)	Project Year	
			Begin	Finish
Nakhon Pathom	375,300	364,200	2507	2516
Kamphaeng Saen	316,000	252,800	2508	2518
Nakhon Chum	289,000	265,000	2505	2515
Ratchaburi (Left Bank)	281,000	258,000	2510	2515
Damnoen Saduak	333,080	333,080	2445	2450
Sum of Phase 1	1,594,380	1,473,080		
Tha Maka	314,400	283,800	2513	2523
Ratchaburi (Right bank)	337,300	303,600	2516	2532
Phanom Thuan	369,200	332,300	2520	2536
Song Pinong	346,400	311,750	2524	2536
Bang Len	351,500	316,350	2526	2537
Sum of Phase 2	1,718,800	1,547,800		
Overall Sum	3,313,180	3,020,880		

Table 3 Large Irrigatin Projects in the Chao Phraya River (2526-2538)

Project Name	Irrigation Area (Rai)
Upper East Bank	
Monorom	130,038
Monorom, Chongkhae	252,786
Chongkhae, Khok Kratheim	251,448
Khok Kratheim, Rueng Rang	373,202
Maha Ratcha	485,400
Lower East Bank	
South Pasak, Tha Luang	507,640
North Rangsit, South Rangsit	971,600
Khlong Dan, Phra Ong Chaiya	1,035,000
Upper West Bank	
Phola thep, Borom That	273,683
Borom That	171,204
Chana Sut, Yang Mani	486,828
Yang Mani, Pak Hai	102,268
Tha Bote	71,474
Sam Chuk	305,000
Pho Phraya	370,000
Pholathep, Tha Bote, Don Chedi	287,325
Lower West Bank	
Bang Bal	137,000
Pak Hai	185,476
Chao Chet-Bang Yeehon, Phraya Banlu, Phra Pimon, Phasi Charoen	1,155,450
Lower West Bank	
Overall Sum	**7,552,822**

Sustainable Development

The Greater Chao Phraya and the Mae Klong irrigation projects are located in the Asian monsoon region with heavy rainfalls due to cyclones from the South China Sea and the Bay of Bangal cause severe flood damages which must be properly mitigated. High tides in the head of the Upper Gulf of Thailand provide strong tidal actions cause problems of salinity intrusions and high rates of sedimentation which should be appropriately alleviated. Analytical and numerical models of interaction of fides and river flow are developed for used as tools in solving the above problems.

1. Flood Mitigation and Management

a) Floods cause high casualties and extensive damage. Any activity which would reduce flood losses would be desirable. AIT River Network Model was developed by Vongvisessomjal and Suppataratarn (1998) to simulate floods of Chao Phraya delta. The model was calibrated with the flood of 1980 and then verified with the flood of 1983. Good agreement between the observed and computed water levels were obtained for both years with the root mean squre errors of about 10 cm in the river and 7 cm in the flood plain.

Physical layout and schematization of the model are shown in Figures 7a and 7b respectively and comparisons of observed and computer water levels in the calibration of the 1980 flood were shown in Figure 8 where cell numbers were shown in Figure 7b. which illustrated flood ware heights attenuated as they propagated from upstream to downstream locations in both rivers and flood plains.

An analytical model describing completely the interaction of flood and tidal waves from the river mouth are successfully developed by Vongvisessomjai and Rojanakamthorn (1989) to mitigate floods of the city of Bangkok using perturbation method and harmonic analysis. Its separated the water levels into nonperiodic and periodic components as well as decomposing the complex tides into their individnal constituents, thus enabling a rigorous comparison to analytical solutions. It was found from the study that the river flow raised the mean water level but damped the tides and reduced their celerities as shown in Figures 9 and 10 respectively.

The zeroth order solution was for mean monthly water levels due to freshwater discharges from upstream which is a straight line with a slope of mean water level $S_{fo} = -u_o^2/[C_z^2(h+\eta_o)]$ shown in Figure 9.

The first order solution was for tides of 4 major constituents (M_2 , S_2 , K_1 and O_1) in each month of 1980-1983 shown in Figure 10; the tide attenuated exponentially $a(x) = a_o \exp(-\mu x)$ where a_o was the amplitnde of tide at the river mouth.

The above results are obtained from harmonic analysis of observed tides in dry and rainy seasons shown in Figure 12 while Figure 11 shown the 5 recording stations of tides in the lower reach of the Chao Phraya river.

The three-dimensional plot of the analytical model of water surface fluctuation in the rainy season with respect to distance and time in Figure 13 while their longitudinal profiles of water level between theoretical computation and measurement on October 15 and 16, 1983 with 3 hour interval are shown in Figure 14.

The analytical model converses the water levels in dry and rainy seasons to more useful discharges in dry and rainy seasons as shown in Figure 15.

The three-dimenriand plot of a numerical model results of water levels with respect to distance and time of the Tha Chin river on January 12-19, 2002 and its longitudinal profiles at 3 hour interval on January 15, 2002 are shown in Figures 16a and 16b respectively.

The three-dimensional plot of a numerical model results of water level with respect to distance and time of the Mae Klong river an January 5-12, 2000 and its longitudinal profiles of 3 hour in terval an January 9, 2000 are show in Figures 17a and 17b respectively. Due to sleeper slope of the Mae Klong, the tidal action cannot go beyond 70 km from the river mouth.

b) Flood management of the Chao Phraya river is presented as follows.

In 1995, there was a severe flood affecting many people all over Thailand. It resulted in extensive flood damage of about 50 billion Baht and the loss of many lives. As a result, the World Bank provided financial support to the Royal Thai Government for a study on Chao Phraya Flood Management Review. The author was invited to serve as the Project Team Leader in order to assist the government in the identification of high priority flood management projects, as well as to chart a conceptual program for basin-wide flood management. The period of study was 16 weeks from August 12 to November 30, 1996. More delails could be seen in a report by Vongvisessomjal et.al (1997).

2. Salinity Intrusion

It can be seen from the three-dimensional plots of water levels with respect to distance and time of the Chao Phraya, the Tha Chin and the Mae Klong rivers in Figures 13, 16 and 17 respectively that these 3 rivers have very high tidal ranges of about 3 m at spring tides which provide strong tidal actions on salinity intrusions in dry season that can domage rices and fruit orchards.

AIT (1978) provided rule curves for controlling maximum salinity intrusions in the Chao Phraya and the Mae Klong rivers in the dry season while TEAM (1997) provided rule curve for controlling maximum salinity intrusion in the Tha Chin river as shown in Figures 18a, 18b and 18c respectively.

RID at present controls the salinity intrusions in the Chao Phraya, the Mae Klong and the Tha Chin rivers by releasing the upstream discharges of 100, 50 and 35 m^3/s respectively.

3. Silt-deposit in Navigation Channel

Due to high tides and their strong actions at the Chao Phraya, the Mae Klong and the Tha Chin rivers, high rate of sedimentation existed in the there river months. The navigation channel of the Chao Phraya river from its mouth to the Bangkok port is 27 km and from the river mouth to the deepsea is 18 km. The high rate of siltation is in the 18 km navigation channel in the sea which is about 4 million cubic meters per year listed in Table 6 taken from an AIT (1994) report on Mathematical Model of Siltation in Second Navigation Channel of Bangkok Port, Research Report No. 282.

As a result of high rate of siltation, a 20 m deposit of Bangkok day from the head of the Upper Gulf of Thailand for more than hundred kilometers upstream from the river mouths to Ayutthaya province.

Table 4. Measured and Computed Annual Siltation Volume in the Existing Bangkok Navigation Channel (AIT, 1994)

Distance along the Channel (km)	Measured Averaged from 1981-1985 (10^3 m^3)	Measured in 1993 (10^3 m^3)	Computed By Model (10^3 m^3)
1	110	79	80
2	190	96	120
3	230	127	200
4	410	91	493
5	515	460	671
6	540	639	494
7	475	456	285
8	310	145	172
9	195	156	353
10	180	155	330
11	215	97	100
12	160	113	72
13	180	115	138
14	205	114	120
15	170	77	65
16	190	87	18
17	80	71	9
Total	**4,355**	**3,078**	**3,720**

Summary

1) FAO initiative that Thailand exporting rice to alleviate world-wide food shortages caused by war has come true as Thailand is ranked first in rice export. The quantity of 5-10 million tons and value of 50-100 billion baht of rice export for the last 10 years from 1996-2005 are listed in Table 5.

2) RID has been working very hard in planning and executing this important irrigation project in the Chao Phraya Delta. Efficient irrigation and flood protection systems have been introduced including a recent set-up of telemetering system of the lower Chao Phraya river in the flood control room of RID. This is a good example of Irrigation Technology for Sustainable Agricultural Development.

3) Excellent analytical and numerical models have been developed to be used as tools for solving future problems in other river basins.

Table 5. Quantity and Value of Rive Export in 1966-2005.

Year A.D.	Quantity (tons)	Value (billion baht)
1996	5,460,219	50.7
1997	5,567,360	65.0
1998	6,540,235	86.8
1999	6,838,793	73.8
2000	6,141,341	65.5
2001	7,691,209	70.1
2002	7,334,448	70.0
2003	7,345,971	76.6
2004	9,989,910	108.3
2005	7,537,341	93.5

Source: Office of Agricultural Economic, 2006

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