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Impacts of Land Cover Changes and Large Reservoirs Development on Streamflow Regime of the Chao Phraya River Basin and Its Tributaries

Nipon Tangtham[1], Samakkee Boonyawat[1], and Pongsak Witthawatchutikul[2]

ABSTRACT

Flow timing parameters in terms of quarter flow interval (QFI) and half-flow interval (HFI) for wet period and five-percent flow interval (5%FI) and one-percent flow interval (1%FI) for dry season were determined basing on cumulative flow of 5-yr interval average for selected observation stations of Ping (P19A), Wang (W4A), Yom (Y3A), Nan (N5A), and lower Chao Phraya basins at C2, C7A, and C15. The investigation was carried out using secondary data of streamflow from 1956-1993 observed by RFD and forest map prepared by RFD. It was found that land-use changes during the past 3-decades shortened wet flow timing which consequently decreased dry flow in those narrow and long basins such as Wang and Yom rivers especially in the drought year. For those river systems having large reservoirs, changes of flow timing was dependent on reservoir regulation, downstream rainfall patterns and characteristics. The impact of forest conversion on flow regime of large river basin as Chao Phraya were deemed less than that of the operation of huge reservoirs.

Key words : streamflow regime, land cover change, Chao Phraya river basin

INTRODUCTION

Impact of deforestation on flow timing has been mentioned in many texts and conference papers. There have been, however, still controversial in Thailand. UNESCO (1991) stated in the report entitled “The Disappearing Tropical Forest” that there has been considerable misunderstanding even among hydrologists and foresters as to how tropical forest or lack of them, affects streamflow. Early thinking was that the presence of a forest in a catchment would slowdown and reduce the flood crests and extend the flow in low-water periods. It should be noted that a forested catchment will definitely show longer and more dry season flow than an adjacent eroded catchment as long as the higher water consumption by the trees is offset by the excellent infiltration opportunities of the forest soils. Conversion to cropping will yield more water in “total” because of the reduced consumptive use. However, if there is considerable overland flow during the rainy season because of degraded soil characteristics a real possibility in the absence of soil conservation measures-then less water will

1 Department of Conservation, Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand.
2 Watershed Research Group, Forest Environment Research Division., Forest Research Office, Royal Forest Department., Bangkok 10900, Thailand.

infiltrate to be available as dry-season flow, despite the limited use by the crops. Ristic and McCan (1995) concluded from their study that forest vegetation is powerful regulative factor in hydrologic processes. Influence of forest vegetation, expressed by retention, has special important on the most sensitive part of runoff process. Forest vegetation balances discharge water in the manner as that a part of precipitation spends in E_t process, interception and great part is accumulated in forest soils, and as small useful water reaches into hydrological system. Forest vegetation significantly decrease velocity of surface water and risk of flood appearance.

Changes in the amount and dynamic behavior of catchment scale runoff after a land-use change may not only be due to alterations to the physical nature of the catchment surface but also natural variability in the climate such as the amount and intensity of incident rainfall or both. Simple comparison of streamflows for separate periods before and after a land-use change will reveal the total change due to both processes (Post *et al*, 1993). Careful interpretation of flow-timing using duration curves, double mass plots and regression models can undoubtedly assist (Bren and Papworth, 1991; Cornish, 1993), but the information gained will be ambiguous if the amount and temporal distribution of rainfall changes over the period of investigation.

In determining streamflow timing, Court (1962), Satterlund and Eschner (1965) and Sopper and Lull (1970) categorized two main indicators for this purpose, i.e., “flow dates” and “flow intervals”. The first one is defined as the date on which a given flow volume of a year has passed. It can be further designed as “half-flow date” and “first and third quartile flow dates” which are defined as “the date on which 1/2, 1/4 and 3/4 of the streamflow of a year has passed, respectively. The flow interval parameter is defined as the shortest number of consecutive days that accounts for “high-flows” and the longest number of consecutive days that account for “low-flows”. The “high-flow interval” can be divided into “half-flow interval” and “quarter-flow interval” which means “the shortest rainy season period that includes 1/2 and 1/4 of annual runoff respectively. The “low-flow interval” can also be divided into 2 parameters- “five-percent-flow interval” and “one-percent-flow interval” which uses for indicating “the longest period, usually in dry season, that account for 5 percent and one percent of annual flow, respectively.

In Thailand, Tangtham (1990) determined the role of forest in Khao Yai National Park on flow regime using “flow date” and “flow interval” parameters as previously described and found that catchment with least forest cover tended to have the shortest half-flow and quarter-flow intervals indicating rapid runoff during wet period. Forest in Khao Yai National Park prolongs the 5 percent-flow interval. Regression analysis showed that only two streamflow timing parameters, i.e., 1/4 flow-date and half-flow date are affected by forest cover. Amount of rainfall particularly in rainy season seems to be a main factor affecting flow regime.

The Chao Phraya River Basin consisting of four main tributary basins, Ping, Wang, Yom and Nan basins, and the lower Chao Phraya is considered to be one of the most important basin supplying water to 16 provinces including Bangkok. This large basin has experienced a great deal of forest conversion, urbanization and industrial development during the last three decades. Water shortage and flood have been faced by both upstream and downstream people almost of every dry and wet seasons and deforestation has been blamed as a cause of this phenomenon even though two large storage dams have been operated since 1965. This paper intented to find out in what extend forest conversion and reservoir development in the Chao

Phraya Basin would affect on streamflow regime so that some recommendation on watershed restoration and water resources development could be made.

The specific objectives of this study are (1) to determine flow-timing parameters in terms of flow-dates and flow intervals of four main tributaries and the lower part of Chao Phraya Basin, (2) to study the impact of land use/cover changes on streamflow regimen of the mentioned basins and (3) to observe the effect of existing large reservoirs on flow regulation.

MATERIALS AND METHODS

All sub-basins of Chao Phraya River Basin as showed in Figure 1 were used as study area. monthly runoff observed at P19A (Ping basin), W4A (Wang basin), Y3A (Yom basin), N5A (Nan basin), and C2, C7A, and C15 of the lower Chao Phraya at Amphoe Muang, Nakonsawan; Amphoe Muang, Angthong and Amphoe Muang, Ayudhaya in different periods ranging from 1956-1993 were employed for plotting and drawing cumulative flow volume.

Trends of land-use change in the Chao Praya basin (C15) were illustrated in Figure 2. Average remaining forest areas for the given periods of each basin were estimated from forest maps provided by Royal Forest Department. Two existing large reservoirs, i.e., Bhumibol Dam in Ping basin and Sirikit Dam in Nan basin were considered as factor controlling flow regimen of downstream.

Parameters used to indicate change in flow regime due to change in land cover are those suggested by Court (1962), Satterlund and Eschner (1965) and Sopper and Lull (1970). The method in determining the impact of land cover change on streamflow timing could be described as follows:

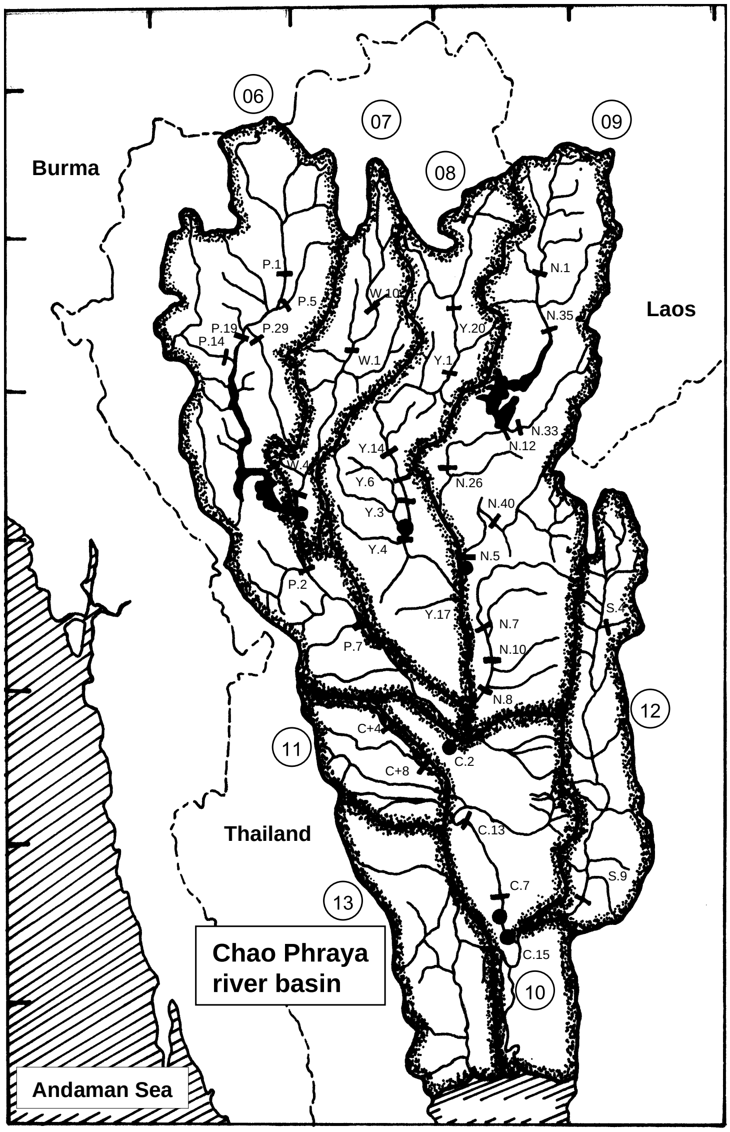
As has been recognized that change of flow dates and flow-intervals could be caused by various factors such as the month that highest rainfall occurs, the amount of annual rainfall, amount of rainfall in each month and the changes of land use within the watershed, variations of momentary peak date, half-flow dates and any particular flow interval are therefore hard to detect which factor or factors significantly effected on.

The study on the impact of land use changes on streamflow timing herein thus based on the assumption that within a given period of consecutive years, e.g., 5 year period, i.e., the average of flow volumes of each of those given periods could be assumed to be treated by the same rainfall characteristics. Only the changes in land use within any given period is then presumed to be a main factor causing the change in streamflow timing.

With the above assumption, cumulative flow volume of each month was calculated starting with April as the first month of the year. Cumulative flow volume of the last month (March) was assigned as 100 percent. Cumulative flow-volumes of each month averaged for the given period (generally 5 yr-period in this study except any of particular one that its consecutive years was less than 5) were then plotted in graphic paper. Lines representing cumulative values of each period was adjusted for determining flow dates and flow-intervals. The method of deriving those streamflow timing was illustrated in Figure 3.

RESULTS AND DISCUSSION

The approximated flow dates and flow intervals at selected stations of the Ping, Wang, Yom, Nan and lower Chao Phraya basins are presented in forms of digital and graphic as shown in Figure 4 to 10 respectively. The impacts on forest conversion and large reservoir development could be described by river basin as follows:



Basin name	km^2	Basin name	km^2
06 Ping basin	33,896	07 Wang basin	10,791
08 Yom basin	23,616	09 Nan basin	34,330
10 Chao Phraya basin	20,125	11 Sakaekrang basin	5,192
12 Pasak basin	16,292	13 Tha Chin basin	13,682

Figure 1 Map showing four main tributaries of the Chao Phraya River basin including the Lower Chao Phraya area.

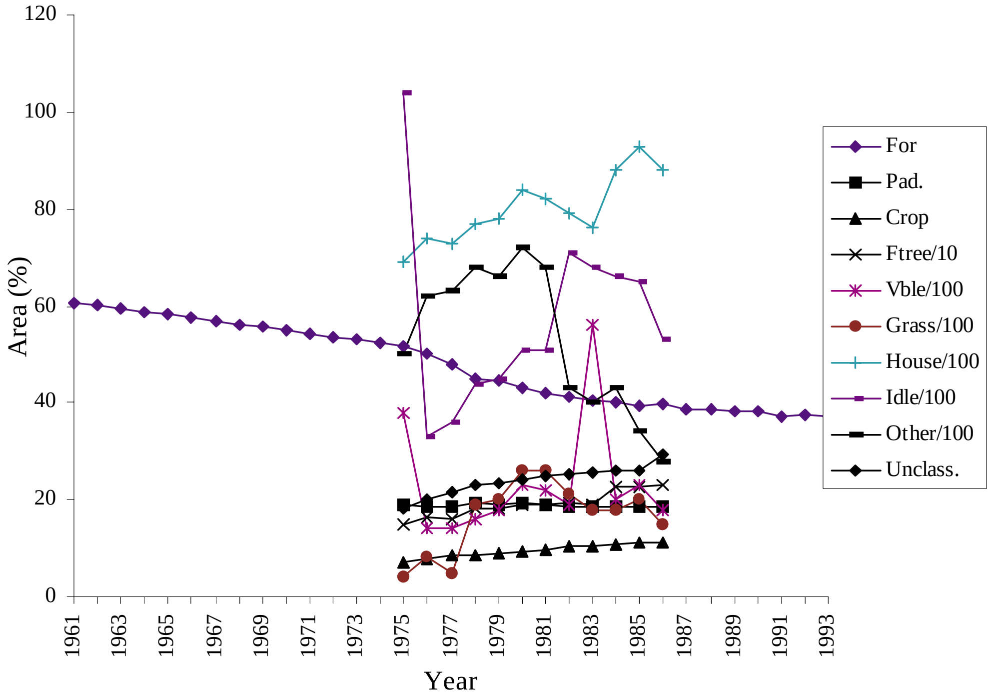


Figure 2 Chages of land-use in the Chao Praya river basin (C15) during 1961-1993.

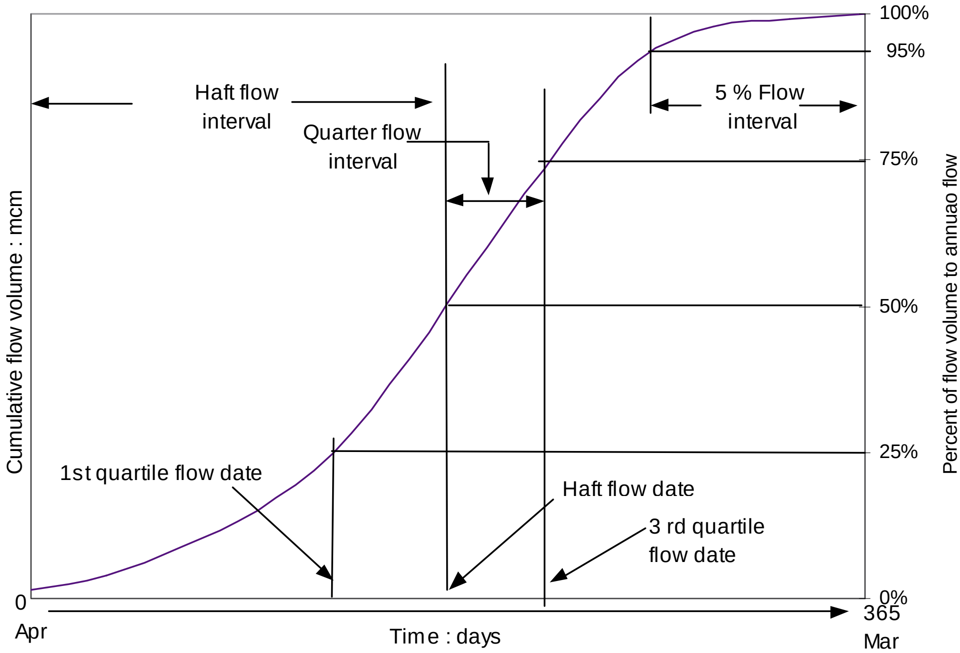


Figure 3 Hypothetical curve of cumulative flow for deriving streamflow timing parameters.

Ping River Basin (upstream of Bhumibol Dam)

The approximated date of the first quartile flow date (1 QFD) observed at P.19A during 1956-1991 was at 136-162 of water-year date. It could occur at any date from August 14 to September 9 with a flow interval of 22-40 days (Figure 3). The half-flow date (HFD) could occur from September 12 to October 8 with a only 52 to 72 days of flow duration.

The third quartile flow date (3 QFD) was approximately occurred at October 16 up to November 4 (during the day 199 to 217 of water year date). This flow date was longer than that of 1 QFD because it is a flow regulated as subsurface and groundwater flow.

The date in which 95% and 99% of annual flow passing through the observation station (P19A), i.e., 95% FD and 99%FD approximately ranged at day 252-278 and 317-335 of water-year (or during December 8 to January 3 and February 11 to March 1) respectively.

Based on the percentage of monthly cumulative flow of 5-yr interval average derived from drainage area of 14,023 sq.km upstream of Bhumibol Dam during 1956-1990, the decrease of forest area from 68% to 48.5% showed no clear picture of changing in flow timing parameters. There was no trend in shortening the high flow intervals and low flow intervals. The one percent flow quantity occurred during the first period of investigation (1956-1960) when forest covered more than 60% indicates more or less the same pattern as that observed during the last period (1986-1990), i.e., about 0.5% MCM and 0.52 MCM for the first and the last observing periods, respectively (Figure 4).

Medium reservoirs namely Mae Ngat and Mae Kwong constructed in 1985 and 1993 (Peetanonchai, 1993) and high infiltration capacity of cultivated soils disturbed by simple tools used by the highland farmers could be the main factors affecting flow regulation.

Wang River Basin

Based on flow observation during 1971 to 1993, there was not much difference of flow interval in terms of QFI, HFI, 5%FI and 1%FI for the first 4 periods during 1977 to 1990, i.e., in the ranges of 28-37, 50-66, 100-120 and 48-60 days, respectively (Figure 5).

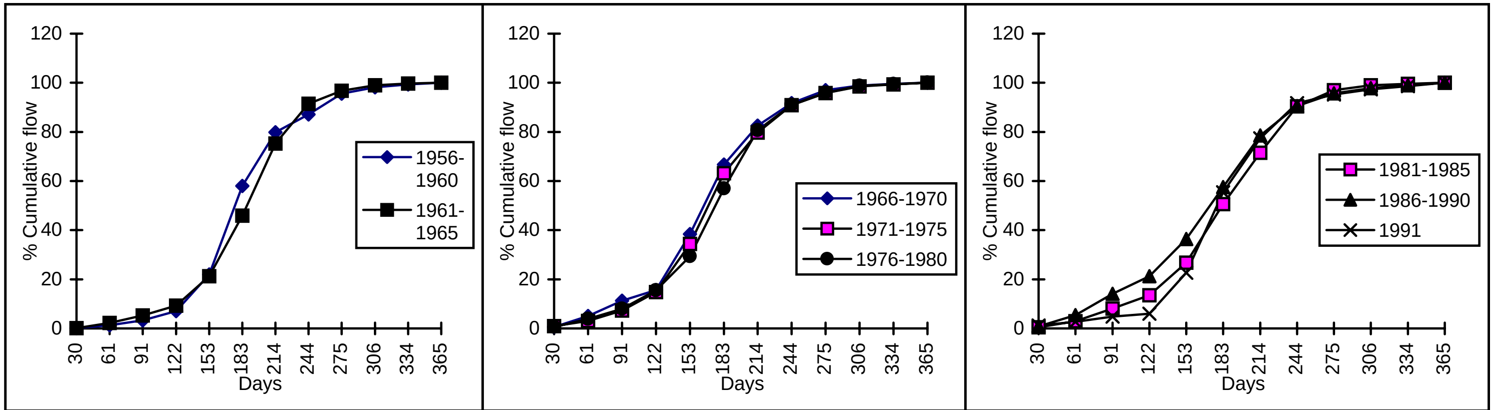
Since 1991, especially in the drought year of 1993, highflow interval was shortened by almost double of the first four periods, i.e., only 18, and 38 days for QFI and HFI, respectively. Also, low flow interval was reduced to 35-59 and 4-13 days for 5%FI and 1%FI, respectively. The low flow in the drought year had been passed or perhaps used up very rapidly compared to the past situation.

The long-narrow shaped watershed without large capacity storage reservoir could be the main factor causing this flow timing phenomena. Forest conversion in such long-narrow watershed and inadequate reservoirs to store flood flow during wet period shortened high-flow interval and subsequently reduced both flow quantity and timing in the dry period.

Yom-River Basin

Although forest area in this basin had depleted from 59% in 1967 to 31% in 1993, it seems a little effect on flow timing could be detected. During 1967-1990, QFD and HFD had occurred in August and September in which the HFI was accounted for 47-68 days. QFI was however shortened to only 38 days in the drought year of 1993 (Figure 6).

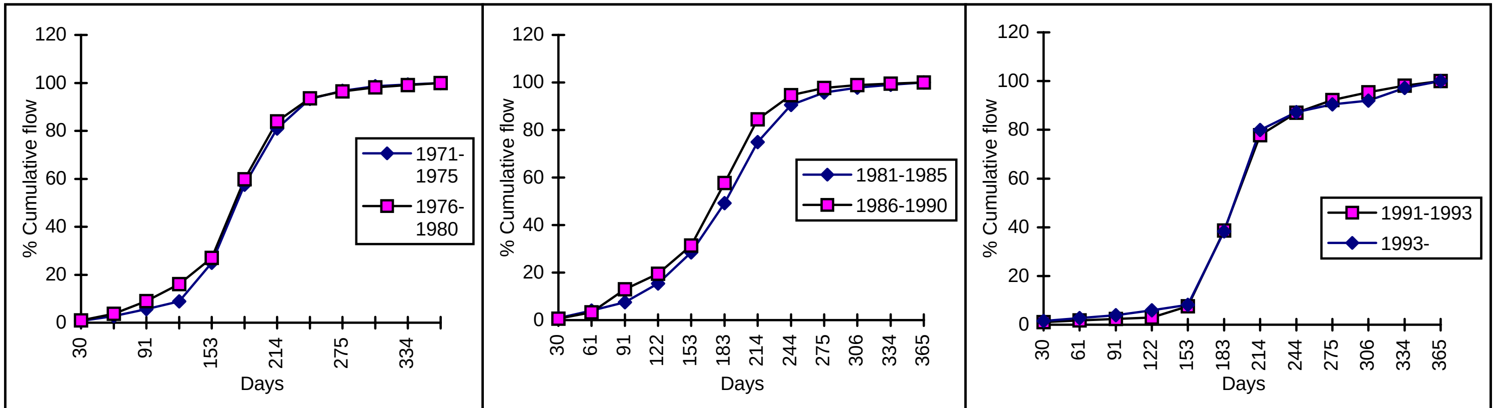
In the dry period, 5%FI was approximately 90-139 days and the 1% FI accounted for 37-81 days. It is obvious that in the drought year of 1993, although flow was generated throughout the year, smaller quantity was observed with more rapidly decreased.



Average percentage of monthly cumulative flow for every 5 year period												
Period	April	May	June	July	August	September	October	November	December	January	February	March
	30	61	91	122	153	183	214	244	275	306	334	365
1956-1960	0.13	1.28	3.31	7.10	21.90	57.97	79.90	87.12	95.54	98.19	99.30	100.00
1961-1965	0.14	2.26	5.24	9.33	21.26	45.94	75.30	91.48	96.79	98.98	99.70	100.00
1966-1970	0.62	5.05	11.26	15.58	38.34	66.70	82.49	91.66	96.98	98.91	99.52	100.00
1971-1975	0.93	3.10	7.32	14.78	34.42	63.20	79.71	90.92	95.85	98.56	99.36	100.00
1976-1980	0.62	3.86	8.01	15.47	29.38	56.98	80.70	91.01	95.93	98.80	99.47	100.00
1981-1985	0.49	2.90	8.12	13.50	26.76	50.57	71.51	90.40	96.94	98.93	99.59	100.00
1986-1990	0.84	5.35	14.06	21.26	36.41	57.48	78.50	90.53	95.71	97.80	99.04	100.00
1991	1.13	2.67	4.81	5.97	22.64	55.46	77.38	91.68	95.28	97.29	98.64	100.00

Approximated flow dates and flow intervals of mean annual flow											
Period	Flow Dates					Flow Intervals (days)				Annual Flow		Estimated Forest cover
	High Flow			Low Flow		High Flow		Low Flow				
	1QFD	HFD	3QFD	95%FD	99%FD	25%Flow	50%Flow	5%Flow	1%Flow	mm	MCM	% of basin
1956-1960	9-Sep	1-Oct	31-Oct	3-Jan	17-Feb	22	52	87	42	173.32	2430.47	66.00
1961-1965	9-Sep	8-Oct	3-Sep	25-Dec	17-Feb	29	55	89	42	217.54	3050.56	62.00
1966-1970	19-Aug	12-Sep	16-Oct	25-Dec	11-Feb	24	58	96	48	225.68	3164.71	54.00
1971-1975	23-Aug	21-Sep	25-Oct	25-Dec	24-Feb	24	63	96	37	330.98	4641.33	56.00
1976-1980	25-Aug	24-Sep	25-Oct	31-Dec	27-Feb	30	61	90	32	205.83	2866.35	54.00
1981-1985	29-Aug	8-Oct	4-Nov	8-Dec	11-Feb	40	67	113	48	178.58	2504.23	51.00
1986-1990	14-Aug	21-Sep	25-Oct	19-Dec	14-Feb	38	72	102	45	185.35	2599.16	49.00
1991-	2-Sep	25-Sep	26-Oct	22-Dec	1-Mar	23	54	99	30	115.83	1624.28	48.50

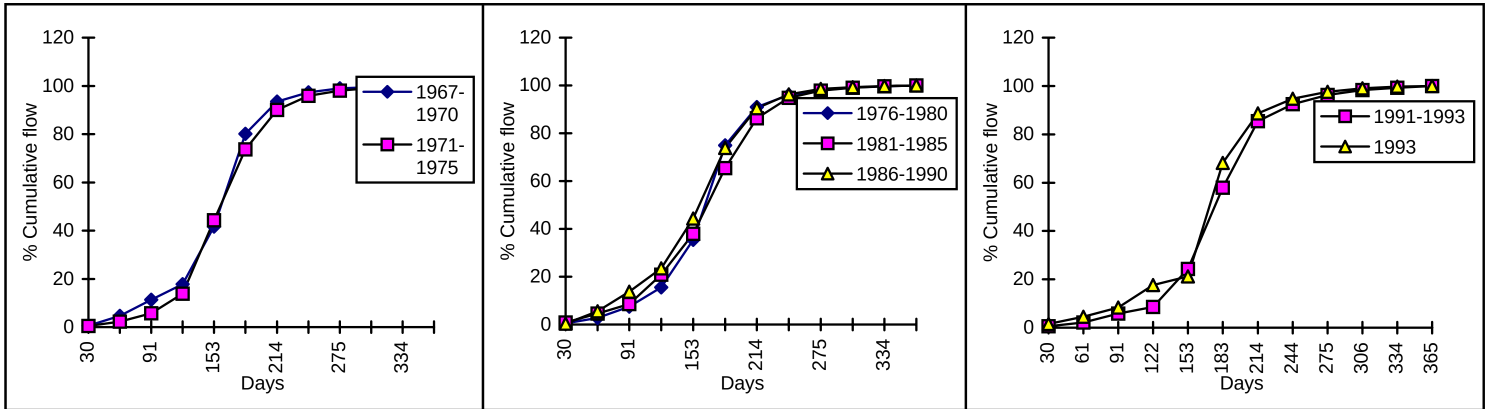
Figure 4 Percentage of monthly cumulative flow for 5-year period of Ping river basin (14,023 sq km) during 1956-1990 (up stream of Bhumibhol dam).



Average percentage of monthly cumulative flow for every 5 year period												
Period	April	May	June	July	August	September	October	November	December	January	February	March
	30	61	91	122	153	183	214	244	275	306	334	365
1971-1975	0.75	2.71	5.59	8.89	25.01	57.50	80.96	93.28	96.73	98.67	99.37	100.00
1976-1980	0.96	3.76	9.02	16.11	26.98	59.80	83.96	93.62	96.41	98.14	99.11	100.00
1981-1985	0.81	3.99	7.53	15.35	28.54	49.25	74.85	90.52	95.77	97.76	99.03	100.00
1986-1990	0.63	3.23	12.95	19.48	31.37	57.64	84.54	94.67	97.72	98.86	99.51	100.00
1991-1993	1.11	1.74	2.31	2.98	7.54	38.69	77.80	87.01	92.21	95.44	98.13	100.00
1993-	1.56	2.75	3.89	5.92	8.10	38.27	79.91	87.23	90.39	91.95	97.14	100.00

Approximated flow dates and flow intervals of mean annual flow												
Period	Flow Dates					Flow Intervals (days)				Annual Flow		Estimated Forest cover
	High Flow			Low Flow		High Flow		Low Flow				
	1QFD	HFD	3QFD	95%FD	99%FD	25%Flow	50%Flow	5%Flow	1%Flow	mm	MCM	% of basin
1971-1975	25-Aug	22-Nov	22-Oct	19-Dec	11-Feb	28	58	102	48	159.13	1671.98	69.00
1976-1980	20-Aug	24-Nov	25-Oct	19-Dec	5-Feb	35	66	102	54	107.27	1127.09	66.00
1981-1985	27-Aug	23-Oct	1-Nov	21-Dec	4-Feb	37	66	100	55	74.15	779.09	64.00
1986-1990	25-Aug	24-Sep	14-Oct	1-Dec	30-Jan	30	50	120	60	85.43	897.61	61.00
1991-1993	19-Sep	9-Oct	27-Oct	31-Jan	18-Mar	18	38	59	13	45.14	474.29	60.00
1993-	19-Sep	9-Oct	27-Oct	24-Feb	27-Mar	18	38	35	4	38.85	408.20	59.00

Figure 5 Percentage of monthly cumulative flow for 5-year period of Wang river basin (10,507 sq km) during 1971-1993 (Tak).



Average percentage of monthly cumulative flow for every 5 year period												
Period	April	May	June	July	August	September	October	November	December	January	February	March
	30	61	91	122	153	183	214	244	275	306	334	365
1967-1970	0.54	4.70	11.34	17.75	41.72	80.12	93.54	97.26	98.96	99.47	99.77	100.00
1971-1975	0.42	2.30	5.79	13.81	44.30	73.64	90.04	95.92	98.03	99.14	99.62	100.00
1976-1980	0.47	2.72	7.53	15.54	35.46	74.97	91.00	95.99	97.94	99.12	99.63	100.00
1981-1985	0.81	4.57	8.55	20.87	37.98	65.38	86.29	94.82	97.82	99.05	99.65	100.00
1986-1990	0.41	5.51	13.69	23.45	44.37	73.80	90.52	96.29	98.51	99.30	99.72	100.00
1991-1993	0.58	2.19	5.79	8.62	24.32	57.96	85.44	92.47	96.23	98.36	99.22	100.00
1993	1.54	4.54	8.40	17.69	21.26	68.22	88.70	94.79	97.60	99.06	99.79	100.00

Approximated flow dates and flow intervals of mean annual flow											
Period	Flow Dates					Flow Intervals (days)				Annual Flow		Estimated Forest cover
	High Flow			Low Flow		High Flow		Low Flow				
	1QFD	HFD	3QFD	95%FD	99%FD	25%Flow	50%Flow	5%Flow	1%Flow	mm	MCM	% of basin
1967-1970	10-Aug	7-Sep	26-Sep	12-Nov	26-Jan	19	47	139	59	168.47	2286.50	58.50
1971-1975	11-Aug	4-Sep	3-Oct	28-Nov	22-Jan	24	53	123	68	253.76	344.56	50.00
1976-1980	13-Aug	10-Sep	30-Sep	22-Nov	9-Jan	20	48	129	81	191.42	2598.80	44.00
1981-1985	6-Aug	6-Sep	13-Oct	30-Nov	24-Jan	31	68	121	66	185.45	2517.80	36.50
1986-1990	2-Aug	4-Sep	2-Oct	30-Nov	9-Jan	28	61	121	81	151.66	2059.60	33.80
1991-1993	30-Aug	22-Sep	20-Oct	31-Dec	22-Feb	23	51	90	37	100.56	1365.67	32.00
1993	2-Sep	18-Sep	10-Oct	30-Nov	9-Jan	16	38	121	81	70.10	952.05	31.00

Figure 6 Percentage of monthly cumulative flow for 5-year period of Yom river basin (13,583 sq km) during 1967-1993.

Forest depletion in this basin seems to have less effect on runoff than that observed in Wang basin even though there was no large reservoir except in the drought year.

Nan-River Basin (Downstream of Sirikit Dam)

Before operating the Sirikit Dam upto year 1956, 25% of annual runoff had passed streamflow observation station at N5A by 26-38 days in rainy season. After reservoir operation, the same flow quantity was extended to 58-77 days while 50% of annual flow which once taking 49-97 days was extended to 120-170 days. This indicates a benefit of Sitikit Dam in delaying flow and reducing flood magnitude during the rainy season (Figure 7).

In the dry season when Nan watershed had been covered with more than 48% of forest area, the 5%FI was observed at about 104-121 days indicating small quantity of flow per day had passed. The 5%FI and 1%FI were shortened to a range of 18-31 days and 3-13 days, respectively after reservoir operation and depletion of forest area from 48 to 30%. Reservoir operation increased flow quantity during dry period with almost uniform distribution (Figure 7) except in the drought year of 1993 when downstream needed larger quantity to alleviate water shortage and salinity intrusion of lower Chao Phraya basin including Bangkok area.

Flow regime of downstream Nan river has been influenced by storage dam in a greater extent when compared to that of deforestation.

The Lower Chao Phraya Basin

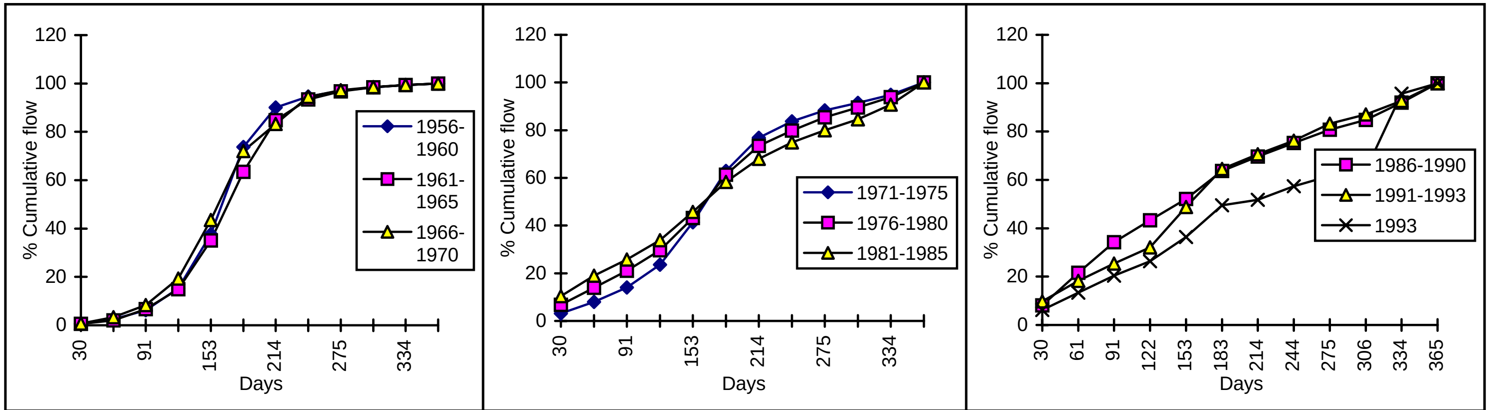
In Figure 8, it was observed that before operating Bhumibol Reservoir (i.e., during 1956-1965) the shortest number of day that 25% and 50% of annual flow had passed the observation station at C2 (Amphoe Muang, Nakonsawan) was approximately 25-26 days and 56-59 days, respectively. After operating flow from the reservoir in 1966, the same parameters of flow intervals were extended to 33-38 days and 79-85 days, respectively. After 1975 when Sirikit Dam had been operated, the mentioned flow intervals were extended to 41-54 days and 98-146 days, respectively (Figure 8).

During the dry period at which 5% and 1% of flow were usually needed longer than 90 days and 31 days, respectively before both reservoirs operation, these flow intervals were shortened to 34-84 and 10-22 days, respectively after operating Bhumibol reservoir. This implies that water that stored during the rainy season was released to downstream in a greater amount than that of summer flow of the passed years. The larger quantity of 5% and 1% in the dry period was found at C2 when the Sirikit reservoir had been operated after 1975. The 5%FI and 1%FI were shortened to only 21-22 days and 7-10 days, respectively with almost uniform distribution throughout the year (Figure 8, during 1976-1990). However, the situation of flow timing had returned to a period prior to reservoir operation in the drought year (in 1993), i.e., there was less daily flow for the 5%FI and 1%FI in 1993.

The same pattern of flow regime was also observed at C7A station (Amphoe Muang, Angthong) (Figure 9) i.e., flood magnitude in terms of 25% and 50% of annual flow decreased while the 5% and 1% of annual flow increased with decreasing flow intervals.

At C15 (Amphoe Muang, Ayudhaya), however, there was not much difference in 25% and 50% flow in rainy season before and after reservoirs' operation.

However, observed data at C15 (Amphoe, Muang Ayudhaya) (Figure 10) indicated that before and after operating Bhumibol Dam in 1964 and Sirikit Dam in 1975, flow quantity passed downstream at C15 was not much different in both the high-flow and low-flow intervals with annual flow ranged between 4134 and 6990 MCM (Figure 10). It might be possible that flow feeding downstream from C7A had been spread out and



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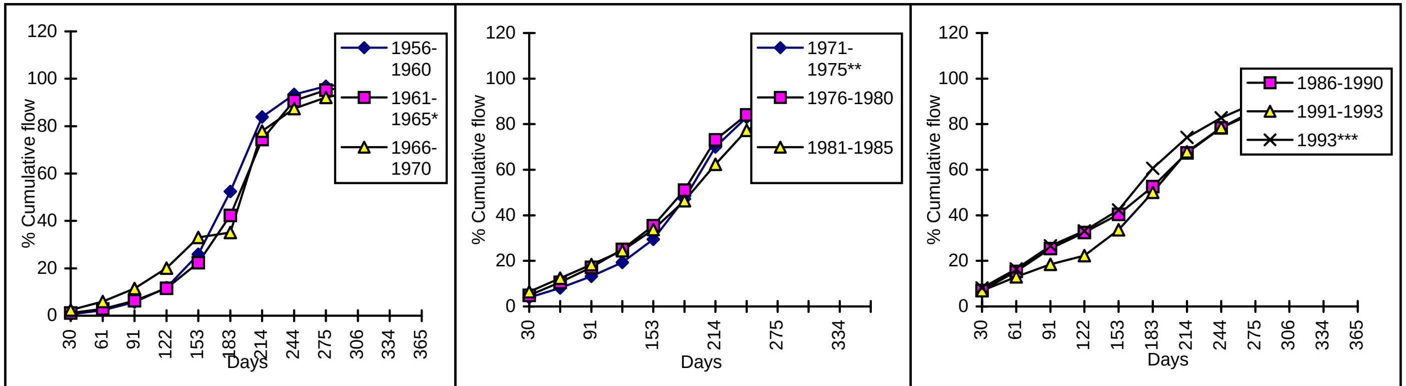
1961-1965	0.61	2.04	6.66	14.86	35.08	63.42	84.85	93.40	96.74	98.39	99.34	100.00
1966-1970	0.71	3.29	8.33	19.29	43.56	72.05	83.26	94.47	97.19	98.53	99.33	100.00
1971-1975	3.17	7.98	13.99	23.60	41.42	62.93	76.80	83.70	88.30	91.46	94.82	100.00
1976-1980	6.75	13.97	21.03	29.69	43.13	61.39	73.46	79.89	85.46	89.54	93.85	100.00
1981-1985	10.44	18.99	25.76	33.91	45.68	58.27	67.99	74.90	79.96	84.50	90.77	100.00
1986-1990	8.09	21.63	34.25	43.27	52.13	63.66	69.62	75.28	80.81	84.81	91.96	100.00
1991-1993	9.74	18.31	25.39	32.12	48.77	64.56	70.64	76.28	83.29	87.10	92.63	100.00
1993	6.22	13.36	20.34	26.37	36.40	49.46	51.71	57.32	61.66	64.01	95.64	100.00

Approximated flow dates and flow intervals of mean annual flow												
Period	Flow Dates					Flow Intervals (days)				Annual Flow		Estimated Forest cover
	High Flow			Low Flow		High Flow		Low Flow				
	1QFD	HFD	3QFD	95%FD	99%FD	25%Flow	50%Flow	5%Flow	1%Flow	mm	MCM	% of basin
1956-1960	18-Aug	13-Sep	2-Oct	1-Dec	19-Jan	26	45	121	71	294.35	7444	78.00
1961-1965	22-Aug	18-Sep	14-Oct	12-Dec	29-Jan	27	53	104	61	332.53	8410	67.00
1966-1970	12-Aug	8-Sep	9-Oct	3-Dec	25-Jan	27	49	118	65	339.06	7927	56.00
1971-1975	5-Aug	12-Sep	10-Nov	20-Feb	16-Mar	38	97	39	15	272.64	6955.6	47.80
1976-1980	16-Jul	12-Sep	14-Nov	6-Mar	25-Mar	58	120	25	6	363.16	9184	41.00
1981-1985	1-Jul	16-Sep	18-Dec	13-Mar	28-Mar	77	170	18	3	328.23	8302.4	36.00
1986-1990	18-Jul	25-Aug	1-Dec	13-Mar	28-Mar	68	166	18	3	221.39	552.8	33.00
1991-1993	30-Jul	2-Sep	23-Nov	8-Mar	21-Mar	64	151	23	10	163.18	4125.15	31.00
1993	24-Jul	11-Oct	9-Feb	28-Feb	18-Mar	79	200	31	13	176.07	4450.58	30.00

Figure 7 Percentage of monthly cumulative flow for 5-year period of Nan river basin (25,294 sq km) during 1956-1993 (down stream of Sirikit dam).

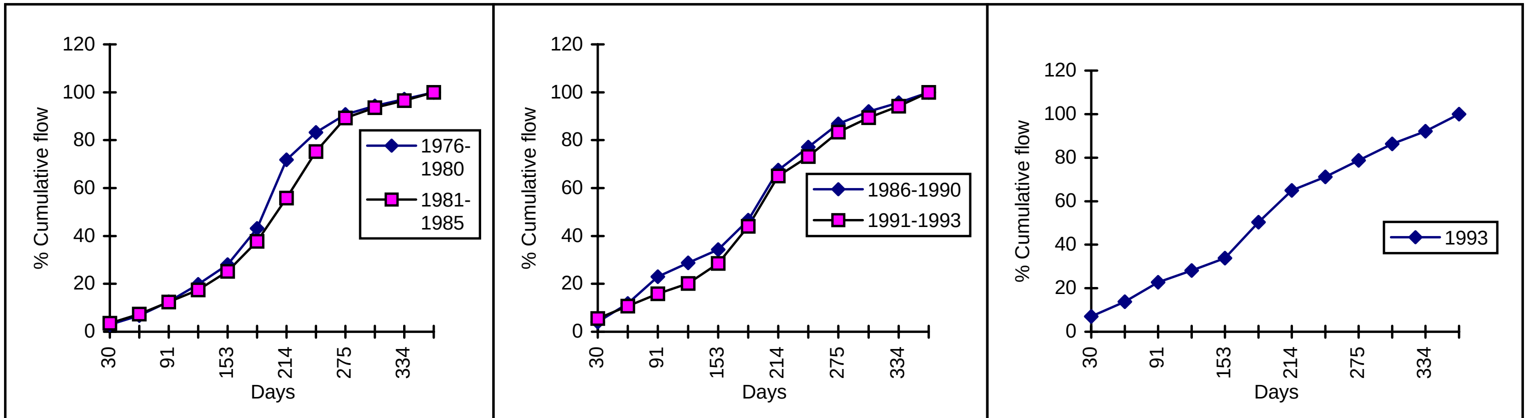


Average percentage of monthly cumulative flow for every 5 year period												
Period	April	May	June	July	August	September	October	November	December	January	February	March
	30	61	91	122	153	183	214	244	275	306	334	365
1956-1960	0.60	2.34	5.74	11.76	25.95	52.44	83.83	93.36	96.88	98.29	99.30	100.00
1961-1965*	1.15	2.87	6.36	11.54	22.37	42.36	74.31	90.71	95.21	97.06	98.46	100.00
1966-1970	2.42	5.95	11.43	20.08	32.99	35.15	77.89	87.39	92.11	95.04	97.44	100.00
1971-1975**	3.92	8.14	13.27	19.31	29.52	47.19	70.05	83.06	89.04	92.42	95.73	100.00
1976-1980	4.87	10.67	17.13	25.05	35.37	51.03	73.08	84.06	89.36	92.58	95.70	100.00
1981-1985	6.41	12.41	18.41	24.47	33.80	46.42	62.36	77.25	84.84	88.46	93.25	100.00
1986-1990	7.08	15.44	25.43	32.43	40.46	52.55	67.39	78.38	85.29	88.62	93.06	100.00
1991-1993	6.96	13.00	18.46	22.36	33.61	50.12	67.90	78.52	86.30	90.00	94.19	100.00
1993***	8.16	16.48	26.66	33.22	42.33	60.54	74.24	82.84	89.36	92.10	95.32	100.00

Approximated flow dates and flow intervals of mean annual flow												
Period	Flow Dates					Flow Intervals (days)				Annual Flow		Estimated Forest cover
	High Flow			Low Flow		High Flow		Low Flow				
	1QFD	HFD	3QFD	95%FD	99%FD	25%Flow	50%Flow	5%Flow	1%Flow	mm	MCM	% of basin
1956-1960	27-Aug	27-Sep	22-Oct	12-Dec	7-Feb	25	56	109	52	181.05	200018.52	66.00
1961-1965*	4-Sep	7-Oct	2-Nov	31-Dec	28-Feb	26	59	90	31	224.5	24822.74	60.00
1966-1970	9-Aug	24-Sep	27-Oct	6-Jan	9-Mar	33	79	84	22	208.97	23105.6	54.00
1971-1975**	18-Aug	4-Oct	11-Nov	25-Feb	21-Mar	38	85	34	10	220.6	24391.52	48.00
1976-1980	1-Aug	27-Sep	7-Nov	25-Feb	21-Mar	41	98	34	10	239.9	26525.5	44.00
1981-1985	31-Jul	4-Oct	25-Nov	10-Mar	24-Mar	52	117	21	7	203.29	22477.57	41.00
1986-1990	27-Jun	27-Sep	20-Nov	9-Mar	24-Mar	54	146	22	7	162.86	18007.27	39.00
1991-1993	4-Aug	27-Sep	10-Nov	7-Feb	3-Mar	44	98	52	28	109.93	12154.85	37.00
1993***	20-Jun	10-Sep	24-Oct	19-Jan	22-Feb	44	126	71	27	93.78	10369.16	36.00

Remark * Bhumibol dam operated in 1965
** Sirikit dam operated in 1975
*** the most recent drougt year

Figure 8 Percentage of monthly cumulative flow for 5-year period of Chao Phraya C2 river basin (110,569 sq km) during 1956-1993.



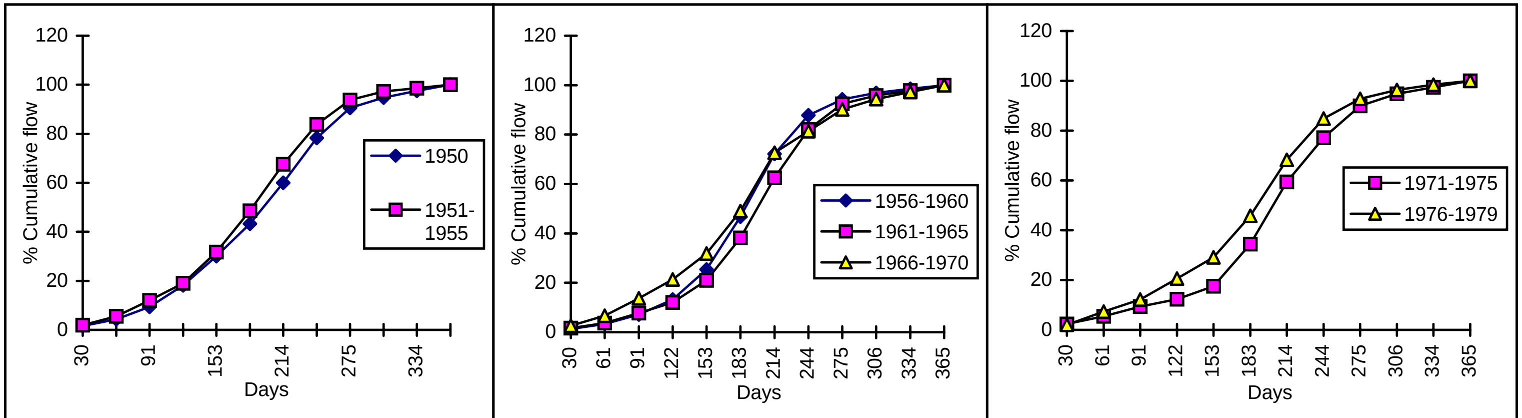
Average percentage of monthly cumulative flow for every 5 year period

Period	April	May	June	July	August	September	October	November	December	January	February	March
	30	61	91	122	153	183	214	244	275	306	334	365
1976-1980	2.96	6.73	12.58	19.82	28.06	43.15	71.81	83.26	90.79	94.28	97.19	100.00
1981-1985	3.53	7.37	12.46	17.43	25.22	37.73	55.86	75.19	89.25	93.51	96.48	100.00
1986-1990	4.10	11.81	22.99	28.76	34.33	46.64	67.56	77.06	86.78	91.97	95.65	100.00
1991-1993	5.52	10.68	15.90	20.16	28.58	43.98	65.10	73.14	83.32	89.42	94.14	100.00
1993	7.06	13.74	22.69	28.16	33.87	50.34	64.92	71.17	78.68	86.36	92.19	100.00

Approximated flow dates and flow intervals of mean annual flow

Period	Flow Dates					Flow Intervals (days)				Annual Flow		Estimated Forest cover
	High Flow			Low Flow		High Flow		Low Flow				
	1QFD	HFD	3QFD	95%FD	99%FD	25%Flow	50%Flow	5%Flow	1%Flow	mm	MCM	% of basin
1976-1980	18-Aug	9-Oct	10-Nov	4-Feb	20-Mar	32	84	55	11	116.2	13697	41.00
1981-1985	31-Aug	21-Oct	10-Nov	14-Feb	22-Mar	40	91	45	9	97.51	11483	38.50
1986-1990	11-Jul	5-Oct	20-Nov	24-Feb	24-Mar	46	132	35	7	71.48	8425.4	36.50
1991-1993	18-Aug	7-Oct	4-Dec	4-Mar	26-Mar	58	108	27	5	50	5902.1	34.50
1993	15-Jul	1-Oct	12-Dec	12-Mar	28-Mar	72	150	19	3	37.11	4379.4	34.00

Figure 9 Percentage of monthly cumulative flow for 5-year period of Chao Phraya C7 river basin (117,888 sq km) during 1976-1993.



Period	April	May	June	July	August	September	October	November	December	January	February	March
	30	61	91	122	153	183	214	244	275	306	334	365
1950	1.52	4.33	9.37	18.11	30.02	43.26	59.98	78.33	90.51	94.79	97.52	100.00
1951-1955	1.96	5.56	12.01	19.03	31.79	48.62	67.60	83.78	93.76	97.27	98.65	100.00
1956-1960	1.27	3.39	7.17	13.24	25.40	46.81	72.18	87.78	94.28	96.86	98.49	100.00
1961-1965	1.70	3.71	7.80	12.01	21.04	38.13	62.55	82.08	92.48	95.76	97.85	100.00
1966-1970	2.67	6.67	13.66	21.30	31.80	48.98	72.65	81.37	90.15	94.34	97.17	100.00
1971-1975	2.38	5.45	9.31	12.28	17.57	34.44	59.44	77.20	89.91	94.80	97.34	100.00
1976-1979	2.07	7.28	12.19	20.62	29.06	45.85	68.34	84.83	92.75	96.38	98.48	100.00

Average percentage of monthly cumulative flow for every 5 year period

Approximated flow dates and flow intervals of mean annual flow

Period	Flow Dates					Flow Intervals (days)				Annual Flow		Estimated Forest cover
	High Flow			Low Flow		High Flow		Low Flow				
	1QFD	HFD	3QFD	95%FD	99%FD	25%Flow	50%Flow	5%Flow	1%Flow	mm	MCM	% of basin
1950	17-Aug	15-Oct	26-Nov	28-Jan	23-Mar	42	101	59	8	49.93	6990.2	-
1951-1955	14-Aug	5-Oct	15-Nov	15-Jan	1-Mar	41	93	75	30	45.92	6428.8	-
1956-1960	29-Aug	4-Oct	7-Nov	5-Jan	14-Mar	34	70	85	17	33.07	4629.8	52.00
1961-1965	6-Sep	15-Oct	20-Nov	27-Jan	19-Mar	36	75	60	12	35.89	5024.6	47.00
1966-1970	10-Aug	30-Sep	9-Nov	27-Jan	18-Mar	40	92	60	13	30.75	4305	43.00
1971-1975	12-Sep	20-Oct	25-Nov	27-Jan	20-Mar	36	74	60	11	32.32	4524.8	38.00
1976-1979	15-Aug	5-Oct	13-Nov	17-Jan	23-Mar	39	90	73	8	29.53	4134.2	35.00

Figure 10 Percentage of monthly cumulative flow for 5-year period of Chao Phraya C15 river basin (140,000 sq km) during 1950-1979.

withdrawn for large area of paddy cultivation before two huge dams construction. The depletion of annual flow downstream at C15 could be due to larger extension of paddy cultivation both in wet and dry seasonal practices.

CONCLUSION

Study on the impact of land cover changes and large reservoir development on flow regimen of the Chao Phraya basin was carried out based on secondary data observed by RID and RFD during 1956-1993. Quater flow interval (QFI) and half flow interval (HFI) in the rainy season and low flow interval in terms of five percent-flow interval (5% FI) and one percent flow interval (1% FI) in the dry season were applied for determining flow timing of four main tributaries of the Chao Phraya basin and lower Chao Phraya river upstream of Bangkok. Results could be summarized as follows:

1) Deforestation in the Ping basin during the past periods showed no clear change in flow regime parameters. Medium reservoir (Mae Ngat and Mae Kwuang) constructed in the last period of investigation and the shifting cultivation using simple tools which caused little disturbance on soil structure of mountainous land would be the main factors effecting such unclear flow behaviors.

2) In the narrow shaped Wang river basin, there was not much difference in the flow interval parameters when the basin had been covered with more than 60 percent of forest area. QFI was however reduced with 20 days of HFI when forest cover was decreased to less than 60%. The 5% FI and 1% FI were also shortened by 20 and 10 days, respectively, indicating more concentration of low-flow during the dry season or stream-water had been used up more rapidly than in the past.

3) There was not much change in the flow timing parameters for Yom river when forest cover had be converted for traditional cultivation from 57% in 1967 to 31% in 1993. In the normal rainfall-year, the HFI ranged approximately 47-68 days but shortened to only 38 days in the drought year of 1993. During the dry period although there have been water running thoughout the year, smaller amount was observed compared to the old days. Forest area depletion in this basin, however, showed less impact on flow interval than in Wang basin.

4) For Nan river where a large dam (Sirikit) was operated in 1975, QFI and HFI were extended from 26-38 days and 45-97 days to 58-77 days and 120-170 days, respectively. In the summer period, more concentration of flow was regulated by reservoir which made the 5% FI and 1% FI shortened than they used to be.

5) Conclusion which could be made based on Ping, Wang, Yom and Nan basing is that land use change had some impacts on flow timing but depending upon the type of crops and practices after conversion, shape of basin and when and how early the rainy season started.

6) In the case of the lower Chao Phraya basin, both reservoirs (Bhumibol and Sirikit) had obvious effect on all flow-interval parameters. Before operating Bhumibol reservoir (during 1956 to 1965), QFI and HFI observed at C2 (Amphoe Muang, Nakhonsawan) ranged in 25-26 days and 56-59 days, respectively. They were extended to 33-38 and 79-85 days, respectively after operating the reservoir. These high flow interval parameters were then extended to 41-54 and 98-146 days after operating Sirikit reservoir. The opposite was observed for low-flow interval parameters. The 5% FI and 1% FI, which were approximately measured at 90 and 31 days in the dry period, were shortened to only 38-84 and 10-22 days, respectively. Both large reservoirs released more concentration of streamflow during the dry period than the nature had been regulated and with uniform flow distribution. The same magnitude of concentration and flow patterns were also found at

C7A station (Amphoe Muang, Angthong).

7) Downstream to Amphoe Muang, Ayudhaya (C15), where irrigated paddy field for dry period had been enlarged during the past decades, all flow-timing parameters show unclear evidence of change before and after operation of both reservoirs but with a smaller quantity. It could be said that wet flow had been regulated by flood plain of lower Chao Phraya basin where water was lost by evaporation and flashed to the sea in almost the same pattern.

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