Kasetsart J. (Nat. Sci.) 32 : 511 - 519 (1998)

Effects of Land Cover Change and Large Reservoir Operation on Water Balance of the Chao Phraya River Basin

Nipon Tangtham and Samakkee Boonyawat

ABSTRACT

Periodical and long-term annual water balance of the Chao Phraya river basin and its tributaries were determined by water balance equation using data on annual basin rainfall and runoff during 1954 to 1993 observed by Meteorological Department and Royal Irrigation Department. Land cover change data during the investigation period were provided by Royal Forest Department and Land Development Department with those recorded by the Office of Agricultural Economic. The results revealed that mean annual rainfall of the Chao Phraya basin ranged between 1,034-1,893 mm and potentially declined with decreasing forest area from 67% in 1961 to 37% in 1993 and insignificant difference in the entire Chao Phraya basin and its sub-basins. In overall, runoff had potentiality to be decreased in every sub-basin and the lower basin particularly for Wang, Yom and the lower Chao Phraya at Ang Thong. E_t component was significantly higher in Wang and the lower Chao Phraya basin whereby E_t were up to 90% of average annual rainfall in the last 2 periods (1986-1993) of which the average annual rainfall was decreased. The greater E_t loss at downstream was perhaps due to the extended area of dry-season paddy cultivation including rapid development of industries and urbanization.

Key words : land use, cover change, water balance, Chao Phrya river basin

INTRODUCTION

Generally, hydrologists consider the water balance as an essential part of hydrological investigation. Watershed scientists always use the component of water budget in terms of runoff and evapotranspiration (E_t) as indicators for analyzing watershed condition and describing watershed ecosystematic function. Water balance of small and medium watersheds have been extensively studied in the past but not for the large basin due to variability of basin rainfall and changes in land cover over time. The results produced by such small watersheds are generally limited for large river basin application. The water balance and hydrologic cycle of large river basins are thus necessary to be observed much more than before (Musiake and Oki, 1995) so that regional impacts of the hydrological behaviors caused by land cover change could be well understood.

Reynolds and Thompson (1984) concluded from several research publications that large scale deforestation often result in site balances. The studies of Shiklomanov and Krestovsky (1984) in Russia using the general water balance equation for long-term period, i.e., P = E forest + R, where P is

Department of Conservation, Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand.

mean precipitation, E forest is mean of total evapotranspiration and R is mean of total runoff into river, showed that forest not only aid runoff control but also increase the total annual water yield by 10% to 15% for completely forested watershed relative to open treeless area. Forest plantation also supported the increasing runoff during dry season while decreasing peak discharge with an increasing annual runoff at about 5-10%. Forest impact on water balance however depends on forest age and species composition; soil properties, and meteorological condition. Forest area percentage per se is not a very reliable predictor. For the same percentage of forest area the water-balance components and streamflow regime may be quite different depending on forest age and species, forest location within the watershed, and soil types.

In contrast to Russian's study, long-term study in 3-small forested subalpine catchments in Switzerland (Burch and Forster, 1995) indicated that the annual water balance is clearly linked with forest cover, i.e., the higher the forest cover the lower the runoff coefficient. In southeast Asia, commercial forest logging and forest conversion would be likely to affect the water budget of forest areas. In Malaysia, the effect of extracting 33 to 40% of forest stocking by selective logging resulted in increasing streamflow by 37% and 70% per year, respectively (Abdul Rahim and Harding, 1992). Converting logged-over forest to agricultural crops such as oil palm and cocoa caused a substantial increase in streamflow ranging from 137 mm to 820 mm per year, depending on the amount of rainfall after operation (Abdul Rahim, 1988).

Regarding degree of water balance disturbance due to change of land cover, Reifsnyder (1984) stated that the single contribution of forest to the water balance is strongly scale-related. In part, this accords with the limited scale on which forest conversion can take place. Very much of the forest effect is nearly local redistribution of precipitation and is also dependent on rainfall type. For various reasons it is contended that the effect of forest conversion will prove to be significant at the mesoscale if at all. A plea is made for investigation at this scale (the large river basin), especially in the tropics.

The Chao Phraya River Basin-the largest river basin in Thailand and one of the field-based experimental site in the tropical monsoon climate selected by the Japan National Committee for WCRR (1994) for investigating Global Energy and Water Cycle Experiment (GEWEX) is employed in this study. The basin has been experienced a great deal of deforestation, water resources development, urbanization and industrial development during the past 3 decades. Flow patterns and characteristics have been altered and those kinds of development have been blamed as a main cause. The main objective of this study is to obtain the water budget components of four main tributaries of Chao Phraya basin including lower Chao Phraya. An attempt was also made for evaluating impact of land cover change and reservoirs' operation on water budget components so that recommendation on watershed resources management as well as water resource development plans could be derived.

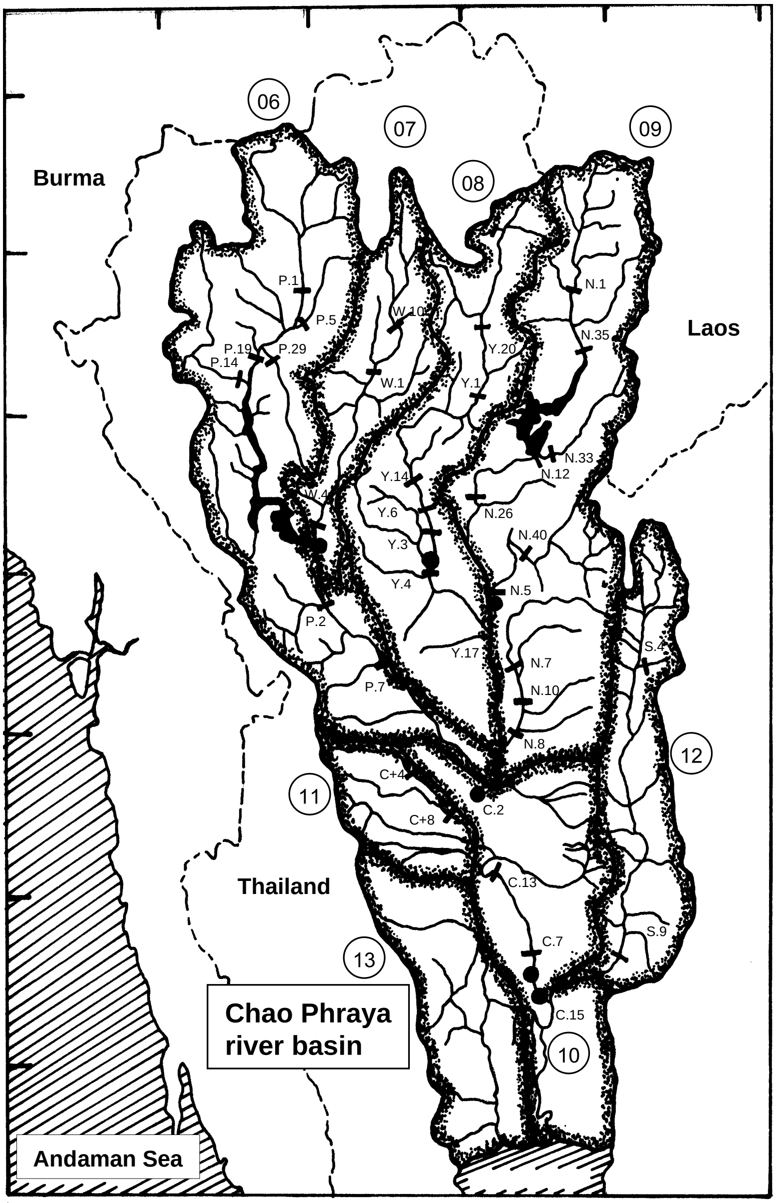
MATERIALS AND METHOD

The Chao Phraya river basin consisting of Ping, Wang, Yom, Nan, Pasak and Sakae Krang basins with an area of approximately 140,000 km^2 as shown in Fig. 1 was employed in this study.

Data collection

The secondary data of rainfall, runoff and change in land use in the basins were collected from the following sources:

1) Monthly and annual rainfall of 8 stations



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.

in the Chao Phraya river basin were collected from Meteorology Department (MD) and Royal Irrigation Department (RID).

2) Monthly and annual runoff observed at P19A (Ping basin), W4A (Wang basin), Y3A (Yom basin), N5A (Nan basin) and C2, C7 and C15 of lower Chao Phraya at Amphoe Muang Nakhonsawan, Amphoe Muang Angthong and Amphoe Muang Ayudhaya, respectively. Periods of runoff measurements were different among stations ranging between 1952 to 1993.

3) Remaining forest area and other land use types in the basin were derived from forest map prepared by RFD and land use map prepared by DLD. Annual reports on the land use survey published by Office of Agricultural Economics (OAE) during 1954-1993 were also used to adjust land use change coresponding to annual rainfall and runoff data.

Data Analysis

Basin annual rainfall and runoff of tributary basins and Chao Phraya basin system and the water budget components were derived by the following procedures:

1) Basin annual rainfall of each basin and of the entire Chao Phraya basin for 35 years were derived from isohyetal map drawn using available software named SURFER together with ARC/INFO.

2) Mean monthly rainfall representing basin rainfall for each basin of all periods was derived by arithmetic average using point rainfall observed in the basin and nearby stations.

3) Due to natural variability of annual rainfall, long term average of 5-yr interval was made for each basin. Nine periods with 5-yr interval, i.e., 1951-1955, 1956-1960, 1961-1965, 1966-1970, 1971-1975, 1976-1980, 1981-1985, 1986-1990, 1991-1993 and 1993 for the most recent drought year of basin rainfall were designed in this study. The 1993 rainfall data was assigned to determine the effect of drought year on water budget.

4) Depth of annual runoff was converted from volume discharge measured at P19A (14,023 km^2), W4A (10,507 km^2), Y3A (13,583 km^2) and N5A (25,294 km^2) for Ping, Wang Yom, and Nan basins, respectively. For the lower Chao Phraya basin, annual and monthly volume discharge at C2 (110,294 km^2), C7A (117,890 km^2) and C15 (140,000 km^2) were used in the study. P19A is at upstream of Bhumibol Dam and N5A is at downstream of Sirikit Dam. The 5-yr period average at the same periods as that made for rainfall data was also used so that the E_t components of water budget can be derived.

5) The 5-yr period average of evapotranspiration (E_t) for each sub-basin was estimated based on long-term water budget equation:

$$E_t = R - Q \pm \Delta S$$

where

E_t = average evapotranspiration of the given period (mm/yr).

R = average annual basin rainfall of the given period (mm/yr).

Q = average annual runoff at outlet of the given period (mm/yr.)

ΔS = change in soil moisture storage (mm/yr) assuming equal zero for the given period

RESULTS AND DISCUSSION

Based on the general long-term period water balance equation, the annual water budget of 5-yr interval average during 1951-1993 for the four main tributaries and lower Chao Phraya river basins corresponding to forest area depletion was formulated in Table 1 and 2, respectively. Overall, annual rainfall over basin areas of C2, C7A and C15 of all periods was greater than 1000 mm except in the drought year of 1993. The average maximum over the respective areas was 1500, 1299 and 1300 mm. It tended to decline for the whole basin systems but with insignificant difference, though forest area in the basin upstream of C2 decreased from about 66% in 1958 to 36% in 1993 (Table 2).

Among the four-main sub-basins, deforestation rate was greatest in Nan basin (from about 78% in 1956 to 30% in 1993), average annual rainfall was, however higher than that of the other three. Variation of annual rainfall in Ping and Nan was also smaller than that in Wang and Yom river basins (Table 1).

Decreasing annual rainfall in Wang and Nan river basin seems to correspond with the depletion of forest area in the basins and the annual runoff of almost all sub-basins was declining especially of Wang and Yom river basins. Statistical analysis, however, indicated insignificant different of annual rainfall due to land cover change in the four basins.

The annual runoff of the lower Chao Phraya river systems declined after 1975. The ratio of water loss was higher, i.e., increasing from about

Table 1 Annual water budget components of 5-yr interval average during 1956-1993 for Ping, Wang, Yom and Nan-the four main tributaries of Chao Phraya River basin.

Budget Component	Water-year Periods									
	1951-55	1956-60	1961-65	1966-70	1971-75	1976-80	1981-85	1986-90	1991-93	1993
Ping basin At P 19A - upstream of Bhumibol Dam (DA=14,023 sq.km.)										
Rain-R (mm)	-	1,057	1,346	1,204	1,292	1,242	1,215	1,059	-	-
Flow-Q_a (mm)	-	173	218	226	331	206	179	185	-	-
Loss-Et (mm)	-	884	1,128	978	961	1,036	1,036	874	-	-
- % of R	-	83.6	83.8	81.2	74.4	83.4	85.3	82.5	-	-
% Forest cover	-	66.0	62.0	59.0	56.0	54.0	51.0	49.0	-	-
Wang basin At W 4A (DA=10,507 sq.km.)										
Rain-R (mm)	-	-	-	-	1,202	1,020	997	1,001	823	716
Flow-Q_a (mm)	-	-	-	-	159	107	74	85	45	39
Loss-Et (mm)	-	-	-	-	1,043	913	923	915	778	677
- % of R	-	-	-	-	86.8	89.5	92.6	91.5	94.5	94.6
% Forest cover	-	77.0	74.0	72.0	69.0	66.0	64.0	61.0	60.0	59.0
Yom basin At Y 3A (DA=13,583 sq.km.)										
Rain-R (mm)	-	-	-	1,052	1,385	1,069	1,179	995	1,023	924
Flow-Q_a (mm)	-	-	-	168	254	191	185	152	101	70
Loss-Et (mm)	-	-	-	884	1,331	878	994	843	922	854
- % of R	-	-	-	84.0	81.7	82.1	84.3	84.7	90.1	92.4
% Forest cover	-	75.0	66.5	58.5	50.5	44.0	36.5	33.8	32.0	31.0
Nan basin At N 5A - downstream of Sirikit Dam (DA=25,294 sq.km.)										
Rain-R (mm)	-	1,448	1,327	1,339	1,396	1,301	1,285	1,203	1,115	1,143
Flow-Q_a (mm)	-	294	333	339	273	363	328	221	163	176
Loss-Et (mm)	-	1,154	994	1,000	1,123	938	957	982	952	967
- % of R	-	79.7	74.9	74.7	80.4	72.1	74.5	81.6	85.4	84.6
% Forest cover	-	78.0	67.0	56.0	47.8	41.0	36.0	33.0	31.0	30.0

85% to 90% for area upper C2 and from 89 to 96% for basin area upstream of C7A. About 2-4% of annual rainfall was however found generating as runoff through C15 since the beginning of record up to 1980 (Table 2).

Statistical analysis indicated that declining forest area upstream of C2 caused increasing dry flow but not for annual yield. Dry flow through C2 was found constantly regulated with 3 and 5 times greater after the Bhumibol and Sirikit Dams were

Table 2 Annual water budget components of 5-yr interval average for the lower Chao Phraya River basin during 1951-1993.

Budget Component	Water-year Periods									
	1951-55	1956-60	1961-65	1966-70	1971-75	1976-80	1981-85	1986-90	1991-93	1993
At C 2 (DA=110,569 sq.km.), Amphoe Muang, Nakhon Sawan										
Rain-R (mm)	1,439	1,265	1,355	1,500	1,463	1,364	1,322	1,196	1,105	978
Flow-Q_a (mm)	-	180	223	208	239	239	202	163	110	94
- Q_d (% of Q_a)	-	3.7	5.9	10.4	14.9	14.5	21.6	21.8	20.4	18.3
Loss-Et (mm)	-	1,085	1,132	1,292	1,263	1,125	1,120	1,033	995	884
- % of R	-	85.5	83.5	86.1	85.2	82.5	84.7	86.4	90.0	90.6
% Forest cover	-	66.0	60.0	54.0	48.0	44.0	41.0	39.0	37.0	36.0
At C 7A (DA=117,900 sq.km.), Amphoe Muang, Ang Thong										
Rain-R (mm)	-	1,138	1,235	1,278	1,247	1,091	1,274	1,299	1,199	992
Flow-Q_a (mm)	-	-	-	-	-	118	97	72	50	37
- Q_d (% of Q_a)	-	-	-	-	-	9.5	14.2	17.8	22.6	28.3
Loss-Et (mm)	-	-	-	-	-	975	1,177	1,227	1,149	995
- % of R	-	-	-	-	-	89.4	92.4	94.4	95.8	96.3
% Forest cover	-	62.0	56.4	51.1	45.0	41.0	38.5	36.5	34.5	34.0
At C 15 (DA=118,600 sq.km.), Amphoe Muang, Ayutthaya (stoped measuring in 1980)										
Rain-R (mm)	1,300	1,143	1,236	1,221	1,289	1,166	1,158	1,101	-	-
Flow-Q_a (mm)	42	38	45	35	36	36	-	-	-	-
- Q_d (% of Q_a)	8.3	7.0	12.5	12.5	9.3	-	-	-	-	-
Loss-Et (mm)	1,258	1,105	1,191	1,186	1,253	1,134	-	-	-	-
- % of R	96.7	96.7	96.3	97.1	97.2	97.2	-	-	-	-
% Forest cover	-	52.0	47.4	43.0	38.0	35.0	32.0	32.0	-	-
Pasak basin (DA=13,780 sq.km.), Kaeng Koy, Sara Buri										
Rain-R (mm)	-	-	-	-	1,160	1,146	1,246	1,206	974	-
Flow-Q_a (mm)	-	-	-	-	131	188	200	132	200	-
- Q_d (% of Q_a)	-	-	-	-	7.5	6.7	8.8	9.7	4.8	-
Loss-Et (mm)	-	-	-	-	1,029	958	1,046	1,074	774	-
- % of R	-	-	-	-	88.7	83.4	83.9	89.1	79.5	-
% Forest cover	-	-	-	-	31.0	26.6	19.0	17.8	16.9	-

Notes :- Rain : estimated by isohyetal map basing on TMD and RID data
Flow : observed by RID ; Q_a = annualflow ; Q_d = dry-period flow (% of Q_a)
Loss estimated by general water balance equation, % of R = % of water loss/annual rainfall
% Forest cover = approximated remaining forest area basing on RFD forest map and statistics reports
* Bhumibol and Sirikit Dams started operating in 1964 and 1974 respectively

operated in 1964 and 1974, respectively. Downstream between C2 and C7 where about 170,000 to 600,000 rais (1 ha = 6.25 rais) of irrigated paddy field (Table 3) had been practiced every dry season.

Annual flow passing C7 was considerably decreased from 116 mm in 1976-80 period to only 37 mm/yr in 1993. Further downstream to where C15 another 200,000 rais of dry-season paddy (Center for Agricultural Statistics, 1994) had been cultivated, annual loss of greater than 90% was

Table 3 Dry period cultivated area of the Greater Chao Phraya Project and some provinces in the lower Chao Phraya basin during 1974-1993.

Calander Year	Dry-period cultivated area in						
	Uthai Thani (rai)	Chai Nat (rai)	Sing Buri (rai)	AngThong (rai)	Uthai Thani Ang Thong[2/] (rai)	Ayutthaya[3/] (rai)	Greater Chao Phraya Project[1/] (rai)
1974	-	-	-	-	-	-	1.259
1975	-	-	-	-	-	-	1.647
1976	-	-	-	-	-	-	2.204
1977	-	-	-	-	-	-	2.226
1978	-	-	-	-	-	-	2.119
1979	-	-	-	-	-	-	3.036
1980	-	-	-	-	-	-	1.322
1981	-	-	-	-	-	-	3.147
1982	-	-	-	-	-	-	3.324
1983	-	-	-	-	-	-	3.216
1984	-	-	-	-	-	-	3.213
1985	-	-	-	-	-	-	3.126
1986	-	-	-	-	-	-	2.765
1987	-	-	-	-	-	-	2.532
1988	-	-	-	-	-	-	2.535
1989	-	-	-	-	-	-	-
1990	28,223	286,325	152,231	140,880	607,659	217,181	-
1991	13,150	68,028	38,675	76,638	169,491	186,514	-
1992	17,085	164,273	41,282	32,901	255,540	214,061	-
1993	16,725	165,642	34,561	37,235	254,231	193,365	-

Note: 1/ The Greater Chao Phraya Project covers cultivated area along lower Chao Phraya river banks from Chai Nat to the outlet of Chao Phraya river

2/ Area in between C2-C7A observation station.

3/ Area in between C7-C15 observation stations

Sources: Data between 1974-1988: from EGAT Working Group (1991)

Data between 1990-1993: from Center for Agricultural Statistics (1994) estimated before and after these huge reservoirs (i.e. Bhomibol and Sirikit) were regulated.

For the Pasak River basin, the lower tributaries of Chao Phraya river systems, annual rainfall ranged from 974-1,246 mm with annual runoff 131-200 mm (or about 18% of annual rainfall). Land-use changes during 1971-1993 increased the wet flow in the upper Pasak indicated no effect in the lower Pasak basin. Only 8% of annual flow was contributed as dry-flow with greater than 90% rapidly flooded to Chao Phraya River.

CONCLUSION

Based on historical data of annual basin rainfall and runoff observed by TMD and RID for more than 35 years, the annual rainfall was the key factor differentiating volume of annual runoff and wet flow for the entire Chao Phraya river basin. Land-use evolution in the basin provided insignificant impact on declining annual rainfall. After operating Bhumibol Dam in 1964 and Sirikit Dam in 1974, although annual runoff passing through Nakhonsawan (C2), AngThong (C7A) was gradually decreased, dry-period flow of about 20% of annual runoff was constantly supplied to downstream. The considerably decrease of annual flow downstream of AngThong (C7A) was perhaps due to large area of irrigated paddy field including rapid development of industries and urbanization. The uniform distribution of monthly runoff and greater amount of dry flow downstream of C2, C7, and C15 was mainly affected by the operation of the mentioned reservoirs.

Average basin annual rainfall in this study was estimated from isohyetal maps drawn using data from the available stations located mainly on lowlands. As greater amount of rainfall has been observed at higher altitude of northern mountain areas, numbers of raingage are thus necessary to be installed. More sophisticate instruments are also needed to obtain higher accuracy not only for studying water balance but also energy balance as well as land-use change.

ACKNOWLEGEMENT

The authors wish to thank the Kasetsart University Research and Development Institute (KURDI) for providing fund for this investigation. The data set used here is from the RID, MD and RFD.

LITERATURE CITED

Abdul Rahim, N. and D. Harding. 1992. Effect of selective logging methods on water yield and streamflow parameters in Peninsular Malaysia. J. Tropical For. Sci. 5: 130-154.

Abdul Rahim, N. 1988. Water yield changes after forest conversion to agricultural land-use in Peninsular Malaysia. J. of Tropical For. Sci. 1: 67-68.

Burch, H. and F. Forster. 1995. Water balance and floods : Results from long-term study in three forested subalpine catchments in Switzerland, p. 19. *In* Caring for Forest : Research in a Changing World. Poster Abstract-Poster 25 : IUFROXX World Congress, 6-12 Aug.1995. Tampere, Finland.

Center for Agricultural Statistics, 1994. Agricultural Statistics in Brief Crop-year 1993/94. Office of Agricultural Economics. Agric. Stat. No. 7/ 1994. Min. Agric. and Coop., Bangkok. 270 p.

Dickinison, R.E. 1980. Effects of Tropical deforestation on climate, pp. 411-441. *In* Blowing in the wind : Deforestation and Long-range Implications, Studies in Third World Societies. No.14, College of William and Mary, Williamsburg, Virginia.

Japan National Committee for WCRR. 1994. GEWEX Asian Monsoon Experiment

(GAME)-a sub-programme of the Global Energy and Water Cyce Experiment (GEWEX). 15 p.

Meteorological Department. 1992. Drought in Thailand. Ministry of Communication, Bangkok (in Thai).

Musiake, K. and T. Oki. 1995. Research Proposal for GEWEX/GAME Hydrologic Cycle and Water Resources in South-east Monsoon Asia. (2nd Draff), Hydrology and Water Resources Engineering, Institute of Industrial Science, Univ. of Tokyo. 20 p.

Reifsnyder, W.E. 1984. Hydrologic process models, pp. 117-127. *In* Reynolds and Thompson (eds.). Forests, Climate and Hydrology: Regional Impacts. The United Nations Univ.

Reynolds, E.R.C. and F.B. Thompson, 1984. Introduction, pp.1-5 *In* Reynolds and Thompson (eds.). Forests, Climate and Hydrology: Regional Impacts. The United Nations University.

Shiklomanov, I.A. and O.I. Krestovsky, 1984. The influence of forest and forest reclamation on water balance, pp. 78-116 *In* Reynolds and Thompson (eds.). Forests, Climate and Hydrology: Reginal Impacts. The United Nations Univ.

Unesco. 1978. Tropical Forest Ecosystems-A State-of-knowlegde Report. UNESCO/UNEP/FAO. Paris. 683 p.

Received date : 23/05/97
Accepted date : 17/04/98