POTENTIAL IMPACT OF SAMBOR DAM PROJECT ON INTERACTION BETWEEN MEKONG RIVER AND TONLE SAP LAKE

Sushu WU[1], Hiroshi ISHIDAIRA[2] and Wenchao SUN[3]

[1]Student member of JSCE, Ph. D. Student, Dept. of Civil and Environmental Engineering, University of Yamanashi (Takeda 4-4-37, Kofu, Yamanashi 400-8511, Japan)
[2]Member of JSCE, Associate Professor, Dept. of Civil & Environment Engineering, University of Yamanashi (Takeda 4-4-37, Kofu, Yamanashi 400-8511, Japan)
[3]Student member of JSCE, Ph. D. Student, Dept. of Civil and Environmental Engineering, University of Yamanashi (Takeda 4-4-37, Kofu, Yamanashi 400-8511, Japan)

Tonle Sap Lake (TSL), an integral part of the Mekong River (MR) Basin, is an important region for social-environmental development of Cambodia. The water flow exchange between TSL and the MR Basin is a vital hydrological process that influences the ecosystem of TSL. Cambodia plan to build a dam for hydropower generation in mainstream of the Mekong River at Sambor which is located in the upstream of the confluence between TSL system and the MR. The objective of this study is to analyze the potential impact of Sambor Dam on interaction between the MR and TSL. The River Lake Water Exchange (RLWE) model was developed to describe this interaction. Then by giving a designed operation rule for the dam, the possible impact was explored through RLWE model. The results show that minimum water level in dry season would rise by 1.2m and peak flood water level would decrease by 1.0m after the installation of Sambor Dam, which would cause damage to ecosystem of TSL.

Key Words : *Mekong River, Tonle Sap Lake, impact, RLEW model*

1. INTRODUCTION

Tonle Sap Lake (TSL) has abundant resources such as forests, fisheries, wetlands, agricultural land, and others. It is an important region for socio-economic development of Cambodia[1), 2), 3)]. In dry season, the water surface area is about 3,000km^2. And during the rainy season, it expands to about 15,000 km^2, largely due to flow discharge from the Mekong River through Tonle Sap River (TSR). This creates an enormous fish breeding, nursing and feeding. About 280 fish species utilize the inundated forests for at least 6 months for their breeding and feeding during the monsoon[4)].

Due to the huge water volume exchange between the Mekong River and TSL, the River-Lake interaction is of great importance for understanding hydrological characteristics of TSL. However, it has already been changed in recent years because of human activities in upstream area of the Mekong River. Construction of hydropower dams and reservoirs, and huge amount of water intake for irrigation result in an increase in dry-season water levels and a decrease in flood peak level. For the period of 1997-2005, Kummu[5)] pointed out that water levels in the dry-season increased by 0.15–0.60 m in TSL, which would, in particular, be harmful to the present lake ecosystem.

In November 2006, on the request of Kingdom of Cambodia, China Southern Power Grid, conducted a feasibility study for the Sambor hydropower project, which is planned to be installed in the Mekong River mainstream at Sambor district, Kratie province, Cambodia[6), 7), 8)]. The site locates to approximately 174km north of Phnom Penh Port, the confluence of the Mekong River and TSR.

According to a report of Mekong Secretariat in 1994 [9)], Sambor Dam will be designed as a "Run-off river dam". However, it will be nearest hydropower project to TSL, and have largest hydropower generation capacity among dam projects along the mainstream of the Mekong.

Several researchers point out possible negative impact of this dam construction on ecosystem. Some researchers thought that the dam would destroy the natural situation for deep pool refuge habitats, migration corridors, and larval drift system, which will influence migratory fish species in the Mekong River. Chan *et al.*[10] consider that any dam on the Mekong mainstream in this part of Cambodia could be disastrous for fisheries, but this site, Sambor, is the worst possible location from this perspective. TERRA[7] even use a subheading "protecting or damning the Mekong?" to protest the project. Most of these researches are from the point of river ecology. Few researches discussed about hydrological changes and consequent impact on environment by Sambor Dam, especially for TSL.

The objective of this study is to investigate the potential impact of Sambor Dam on TSL. Firstly, a River Lake Water Exchange (RLWE) model was developed to simulate interaction between the Mekong River and TSL. Then the impact of Sambor Dam on volume and water level of TSL was explored by RWLE model.

2. STUDY AREA AND METHODOLOGY

(1) Study Area

Tonle Sap Lake (**Fig.1**) is the largest freshwater lake in Southeast Asia. It is located in the northwest part of Cambodia, which is an integral part of the Mekong River. Mekong River is among the largest rivers in the world. It originates from Tibaetan Plateau in China, flows along the border between Thailand and Laos, and then into Cambodia. The confluence of Mekong River and Tonle Sap River is at Phnom Penh Port[8].

(2) Water Level-Volume relationship

The relation between Water Level (WL) and Volume (V) is essential for have a better understanding of hydrological cycle of TSL system. Currently, only the WL-V relationship of TSL
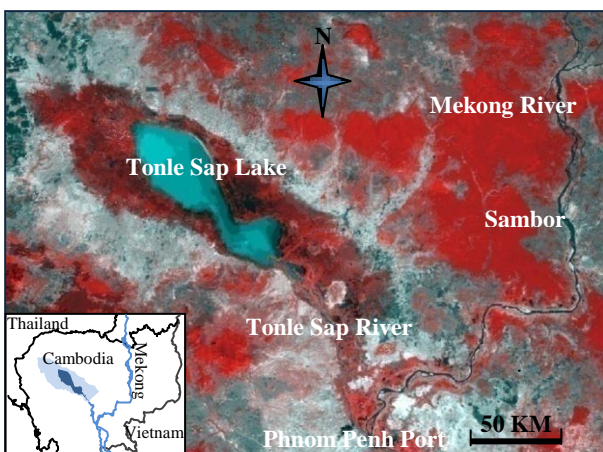

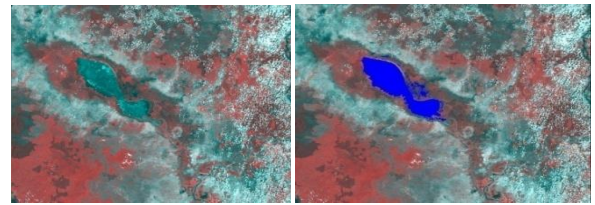Fig.1 MODIS image of Tonle Sap Lake on January 17, 2005

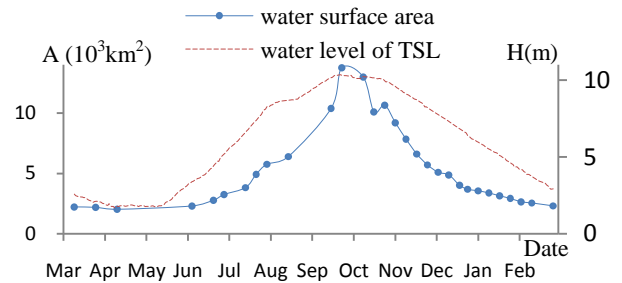**Fig.2** Extract water surface of TSL on March 11, 2000

Fig.3 TSL area variation from March 2000 to March 2001

available. As the human activity increase in the surrounding area of TSL and the Mekong River , the WL-V relation of TSL have been changed in the past decades. Therefore, it is desired to renew the relation based on information from recent years.

Thirty MODIS images for the period of March 2000 to March 2001 were collected to extract water surface area of TSL. Since the reflectance of water is very low in the reflective infrared bands, and the majority of land covers are of higher reflectance, it is very efficiency to distinguish water surface and land area by MODIS. Unsupervised classification method was used to identify water area in every image. An example is demonstrated in **Fig.2**: Left image is the original MODIS image; the blue part in the right image is the water surface area of TSL area being extracted. The extracted water surface area time series is showed in **Fig.3**. By sorting the derived water surface area in ascending order, volume of water between two adjacent water surface areas in the area sequence is computed as follow:

$$\Delta V = \Delta H \times \frac{1}{2}(A_1 + A_2) \qquad (1)$$

where $V(10^9 \mathrm{m}^3)$ is the water volume, A_1 and A_2 are the two water surface areas (10^3 km^2), ΔH is the difference between gauged stages at TSL on the dates when the two images were captured. By sum this volume for each two adjacent water surface area, the corresponding total water surface volume of TSL for each images is obtained. Then the 3$^{\mathrm{rd}}$ order polynomial was applied to describe WL-V relation between water level at Kompong Luong station and water volume of TSL:

$$V = 0.0626H_{KL}^3 - 0.6209H_{KL}^2 + \\ 4.6267H_{KL} - 3.7625 \qquad (2)$$

where V is water volume of TSL (10^9m^3), H_{KL} is gauged stage at Kompong Luong station. A good statistical fit exist for the WL-V relation ($R^2 =0.99$).

(3) RLWE MODEL

a) Basic concept

RLWE model can be used to simulate the balanced system of the interaction hydrologic factors in the circumference of TSL (**Fig.4**).

The balanced system can be described as the following equation:

$$Q_i^{t_i} + Q_{FP}^{t_i} + P_{t_i} - E_{t_i} \pm Q_{PK}^{t_i} = (V_{t_{i+1}} - V_{t_i})/\Delta t \qquad (3)$$

where $Q_i^{t_i}$ is the discharge from the tributaries at t_i, $Q_{PK}^{t_i}$ is the discharge in Prek Kdam station at t_i, when normal flow (MR to TSL) in TSR "$\pm$" is "+" and reverse flow (TSL to MR) is "-", $Q_{FP}^{t_i}$ is the inflow from floodplain at t_i, P_{t_i} is the precipitation of TSL at t_i, E_{t_i} is the evaporation of TSL at t_i, V_{t_i} is the water volume of TSL at time t_i, Δt is the calculate time interval. One variable "δ_i" is used in RLEW model, which can be derived from the following equation:

$$\delta_i = Q_i^{t_i} + P_{t_i} - E_{t_i} \qquad (4)$$

This study make an assumption: δ would not be changed after the dam operation. Based on Eq.(3), after input $Q_{FP}^{t_i}$, $Q_{PK}^{t_i}$ and V_{t_i}, δ_i can be obtained. By input δ_i and Q_{PPP}*(discharge of Phnom Penh Port be changed by human activity such as dam operation) to RLEW model, water volume of TSL after dam operation can be calculated (**Fig.5**).

Any items of this system changed would lead a new water volume of TSL. The interaction between water levels along TSR and the Mekong River need to be discussed: (1) H_{PPP}-H_{PK}-H_{KL}; (2) H_{PPP}-H_{KC}. Any change on these water levels would cause a variation on Q_{PK} and Q_{FP}. The balanced system and volume of TSL also will be changed. In case of Q_{PPP}* be put into RLWE model, the H-Q relationship of Phnom Penh Port need to be obtained.

b) RLWE model structure

The output and input data of RLWE Model are showed in **Fig.5**. RLEW model structure can be described as follow:

b.1) Discharge in Tonle Sap River
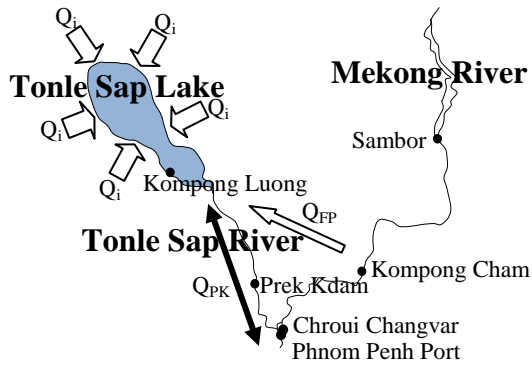
Among the River-Lake interaction, the

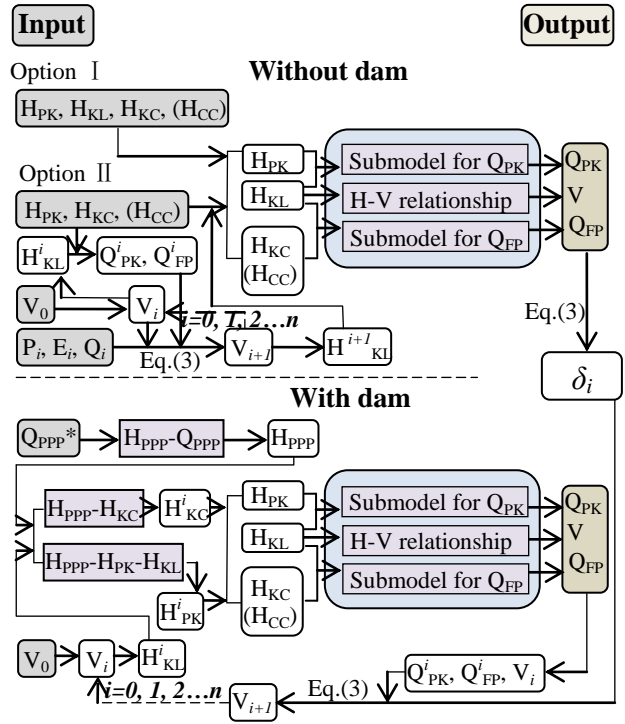**Fig. 4** Balanced system of RLWE model

Fig. 5 RLEW model structure

discipline of discharge flow through TSR is of paramount importance. This study set Prek Kdam gauging station as the control station of TSR. In wet season, water flow from river to lake, the lake serves as an efficient flood reservoir, and in dry season, reversed flow exists in TSR, support water to downstream for regional agriculture. The water level difference between river and lake is the key point, this study use the water level in Phnom Penh Port and Kompong Luong represent the water level of river and lake, respectively.

The equations[11] for discharge in open channels can be generally expressed as:

$$Q = K \times A \times R^\alpha \times S^\beta \qquad (5)$$

where Q is discharge (m³/s), K is a coefficient, A is cross-sectional area (m²), R is hydraulic radius (L), α and β are exponents. S is friction slope, which can be derived from the following equation:

$$S = \Delta H / L \qquad (6)$$

ΔH here is water level difference between Prek Kdam and Kompong Luong station, L is the distance between Prek Kdam and Kompong Luong station. By input S into Eq.(5), discharge can be expressed as:

$$Q = f(H) \times \Delta H^\beta \qquad (7)$$

Observed discharge and water level at Prek Kdam station in 2005 were used to get the following equation for Q_{PK}:

$$\begin{cases} Normal\ Flow: \\ \quad Q_{PK} = 486.84 \cdot H_{PK}^{1.4545} \cdot (H_{PK} - H_{KL})^{0.5} \\ Reverse\ Flow: \\ \quad Q_{PK} = 74.453 \cdot H_{PK}^{2.3842} \cdot (H_{KL} - H_{PK})^{0.78} \end{cases} \qquad (8)$$

Q_{PK} is discharge in Prek Kdam station (m³/s), H_{PK} (m)and H_{KL} (m)is water level in Prek Kdam and Kompong Luong station, respectively.

b.2) Flood plain discharge

Based on Inomata *et al.* [12], discharge from floodplain flow into TSL uses the following equation:

$$Q_{FP} = 0.6612\left(Q_{KC}^{i-1} - Q_{CC}^{i-1}\right) - 2625.4 \quad (9)$$

where i is time step on a daily basis, Q_{FP}^{i}(m³/s) is discharge from flood plain on the date i, Q_{KC}^{i-1}(m³/s) and Q_{CC}^{i-1}(m³/s) are discharges at Kompong Cham and Chroui Changvar on the date *i-1*. In case where the water level data for Kompong Cham are available while the water level data for Chroui Changvar are not available, the equation based on the Kompong Cham water level data collected two days earlier was used as the follow equation:

$$Q_{FP}^{i} = 1196.2(H_{KC}^{i-2} - 12.0) \quad (10)$$

where H_{KC}^{i-2}(m) is water level in Kompong Cham on the date *i-2*.

b.3) H-Q relationship of Phnom Penh Port

There are insufficient hydrological data in TSL and its surrounding area, especially the observed discharge data. This paper uses the relationship between H_{PPP} and H_{KC}-H_{PPP} published by Mekong River Commission in 1970 [13] to calculate Q_{PPP}. After regression analysis, the discharge in Phnom Penh Port station (Q_{PPP}(m³/s)) is given as:

$$Q_{PPP} = (11.0869 \times H_{PPP} + 37.4245)^2 \times$$
$$(H_{KC} - H_{PPP})^{0.4569} \quad (11)$$

where H_{PPP} (m) and H_{KC} (m) are water levels at Phnom Penh Port and Kompong Cham station respectively. By putting the observed daily H_{PPP} and H_{kc} from 1991 to 2002, calculate the discharge at Phnom Penh Port station in these 12 years. Use the discharge and the water level at Phnom Penh Port gauge to fitting the H-Q curve:

$$Q_{PPP}^{up} = 8 \times 10^{-14} \times H_{PPP}^3 - 8 \times 10^{-9} \times H_{PPP}^2$$
$$+0.0004 \times H_{PPP} - 0.1985 \quad (12a)$$
$$Q_{PPP}^{down} = 3.1413\,ln(H_{ppp}) - 24.074 \quad (12b)$$

The discharge was divided into two period: Q_{PPP}^{up} is discharge in the period from minimum to peak discharge, Q_{PPP}^{down} is in the discharge decrease period after the peak discharge, the correlation coefficient are 0.997 and 0.988 during up and down period, respectively.

b.4) H_{PPP}-H_{PK}-H_{KL} and H_{PPP}-H_{KC} relationship

As TSR is the link of TSL and the Mekong River, Phnom Penh Port, Prek Kdam and Kompong Luong stations are used as the representative stations to connect the river and lake. Observed daily water level data of these three gauges from 1996 to 2004 were used to get a regression equation, with a correlation coefficient of 0.96.

$$H_{PK} - H_{KL} =$$
$$0.7361 \times (H_{PPP} - H_{KL}) + 0.1573 \quad (13)$$

Daily observed water level data in Phnom Penh Port and Kompong Cham station in 1993-2004 were used to generate a regression equation for the relationship of these two stations.

$$up: H_{KC} - H_{PPP} = -0.078 \times H_{PPP}^2$$
$$+1.3237 \times H_{PPP} + 0.2065 \quad (14a)$$
$$down: H_{KC} - H_{PPP} = 0.018 \times H_{PPP}^3 - 0.2075$$
$$\times H_{PPP}^2 + 0.6329 \times H_{PPP} + 1.0522 \quad (14b)$$

where "up" and "down" is the discharge increase and decrease period respectively, the correlation coefficient of the up equation is 0.92 and the down equation is 0.94.

3. RESAULTS AND DISCUSSION

(1) Validation for RLWE model

There are insufficient observed discharge data in TSL for validating RLWE model. Only observed discharge data in 2005 are available. **Fig.6** shows the observed discharge and simulated discharge by Eq.(8) for 2005. The flows larger than zero are normal flow and lower than zero are reverse flow. The mean error is 9%. By input daily observed water level data at Prek Kdam and Kompong Luong station from 1996 to 2004, the water volume of TSL and discharge at Prek Kdam are obtained as shown in **Fig.7**, the discharge above the abscissa axis is normal flow, the others is reverse flow.

$$mean\ error = \frac{1}{N}\sum_{i=1}^{N}\frac{|Q_{obs} - Q_{cal}|}{|Q_{obs}|} \quad (15)$$

(2) Impact analysis of Sambor Dam project
a) Restoration of historical discharge data of Sambor site

Due to no observed data at Sambor site, a simple way used to roughly estimate the discharge based on the catchment area:
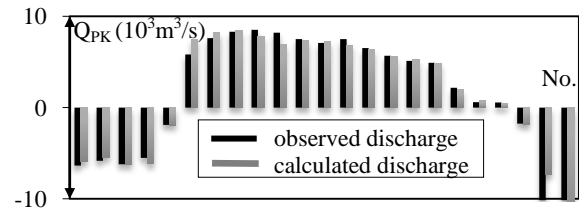

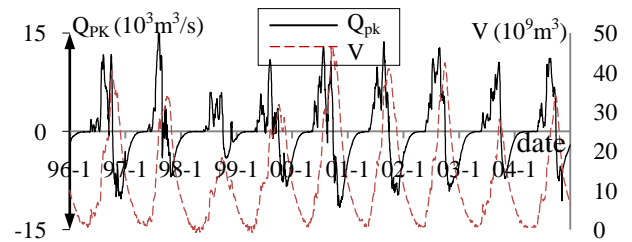**Fig.6** Calculated and observed discharge of Prek Kdam in 2005

Fig.7 Water volume of TSL and discharge at Prek Kdam calculated by RLWE mode

$$Q_{SAM}^i = Q_{PPP}^i \times \frac{A_{SAM}}{A_{PPP}} \qquad (16)$$

where Q_{SAM}^i is daily discharge at Sambor, Q_{PPP}^i is the discharge at Phnom Penh Port, A_{SAM} and A_{PPP} are the catchment areas (km²) of Sambor and Phnom Penh Port respectively. Based on initial design[9], Sambor Dam site have a catchment area of 646,000km². According the Lower Mekong Hydrology Yearbook, catchment area of Phnom Penh Port is 663,000 km².

b) Scenario setting

The theoretical power derived from the water fall depends upon the height and the rate of flow. The available hydropower is calculated from the following formula:[14),15)]

$$P = 9.8 \times r \times q \times h \qquad (17)$$

where P is theoretical output power (kW), q is water flow rate (m³/s), h is water head (m), and r is overall power generation efficiency, which is set to 90% here. According to the report "Mekong Mainstream Run-of-River Hydropower" published by Mekong Secretariat in 1994[9], the water head is roughly equal to 40m and one of designed hydropower capacity is 2500MW. Based on Eq.(17), the designed discharge ($Q_D=q$) is 7102m³/s, for which the possible impact is analyzed.

One simple hypothetical hydropower dam operation rule was designed: In wet season, when inflow is larger than 7102m³/s, appropriate part of daily excessive inflow will be kept in the reservoir, which will be release in dry season to maintain the discharge at the level of 7102 m³/s. The discharge in Sambor Dam site after dam operation can be derived from the following equation:

$$Q_{SAM}^{*i} = \begin{cases} Q_D, & Q_{SAM}^i < Q_D \\ Q_{SAM}^i - \left(\frac{V_2}{V_1}\right)(Q_{SAM}^i - Q_D), & Q_{SAM}^i \geq Q_D \end{cases}$$

$$V_1 = \int_{1\,year} q_e^i dt \qquad V_2 = \int_{1\,year} q_r^i dt$$

$$q_e^i = \begin{cases} 0, & Q_{SAM}^i < Q_D \\ (Q_{SAM}^i - Q_D), & Q_{SAM}^i \geq Q_D \end{cases}$$

$$q_r^i = \begin{cases} 0, & Q_{SAM}^i \geq Q_D \\ (Q_D - Q_{SAM}^i), & Q_{SAM}^i < Q_D \end{cases} \qquad (18)$$

where Q_{SAM}^{*i} and Q_{SAM}^i are discharge (m³/s) in Sambor site with and without dam operation respectively. q_e^i and q_r^i are excessive and recruitment discharge (m³/s) respectively. V_1 and V_2 are water volume (m³) integral of q_e^i and q_r^i respectively.

The impact of Sambor Dam operation on discharge in 1985 is shown in **Fig.8**. In this case, 22% of the daily excessive inflow was kept in the reservoir to maintain the hydrology power.

Observed data in TSL system is scarce, especially continuity data series. Only daily observed water level data sets in Kompong Cham
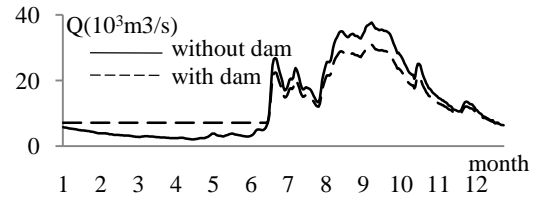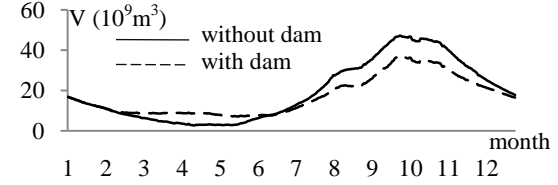

Fig. 8 Discharge in Sambor with and without dam in 1985

Fig.9 Water volume of TSL with and without dam in 2000

are available[12)] in 1985-2004. The data sets are used to analyze flood frequency in this region. Based on derived flood frequency curve of Kompong Cham, year 2000 and 1998 were selected as typical 1-20 wet year and typical 1-20 dry respectively, for which the impact of Sambor Dam on interaction between TSL and the Mekong River was analyzed.

c) Potential impact on natural environment

According to the calculated discharge of Sambor, discharge in Phnom Penh Port station can be derived from the following equation:

$$Q_{PPP}^* = Q_{SAM}^* + (Q_{PPP} - Q_{SAM}) \qquad (19)$$

where Q_{PPP}^* and Q_{PPP} are discharge in Phnom Penh Port station with and without dam operation, respectively. Q_{SAM}^* and Q_{SAM} are discharge in Sambor site with and without dam operation, respectively. By putting Q_{PPP}^* to RLWE model, water volume was calculated. **Fig.9** shows the daily water volume variation of TSL in 2000 with Sambor Dam working or not. Obvious water volume increase in dry season and decrease in flood season can be found in this figure.

For the typical wet year 2000 and typical dry year 1998, the maximum and minimum stage at Kompong Luong, the period for TSL within different water volume level and the period of flood plain exist with and without dam installation are shown in **Table 1**. The extent of hydrological variation will decrease if the dam exists. The time period for high water level (V>40×10⁹ m³) and low water level (V<10×10⁹ m³) is shorter than natural situation. The water level would change from the lowest water level in typical dry year 1.2m to the highest water level in typical wet year 10.4m under natural situation. However, after dam operation, the range of variation would change to 2.4m-9.4m.

Minimum water level of TSL in dry season would rise by 1.2m (2.4m-1.2m), which would cause permanently inundated large areas, rendering it inaccessible to floodplain vegetation and eroding the productivity basis of the ecosystem, the lake extension would destroy considerable areas of

Table 1 Influence of TSL volume characteristic

	1998 Nature	1998 With dam	2000 Nature	2000 With Dam
Max H	6.9m	6.3m	10.4m	9.4m
Min H	1.2m	2.4m	1.7m	3.3m
V<10	217 days	252 days	142 days	145 days
10<V<20	148 days	133 days	72 days	87 days
20<V<30	0	0	46 days	79 days
30<V<40	0	0	51 days	55 days
V>40	0	0	55 days	0
Flood Plain	4 days	4 days	114 days	109 days

gallery forest stripe surrounding the lake in the floodplain[16].

Maximum TSL water volume in wet season would decrease ($10.7 \times 10^9 m^3$) and peak flood water level would have 1.0m lower(10.4m-9.4m). The relationship between the maximum flood level in wet season and the fish catch shows that a permanent lowering of the average peak flood levels would result in a proportionally lower fish catch. Because of the primary reason for the enormous quantity of fish in TSL is the monsoon which annually swells the lake area and the temporary access to enormous quantities of food drives the huge production of fish[17].

The period that flood plain exists does not show a signification change. In flood season, natural inflow into reservoir is enough to generate the electric power, for that reason, the discharge in peak time would not change a lot. Also, discharge and water level in Kompong Cham station would not have a large alteration, which decide the flood plain exist duration time(when $H_{KC} \geq 12$). Therefore, most of the water exchange between river and lake is through TSR, nevertheless, the dam would still bring impact on TSL area.

4. CONCLUSION

In this study, the potential impact of Sambor Dam on interaction between TSL and the Mekong River was analyzed. RLWE model was developed to simulate the interaction. By applying RLEW model, the hydrological characteristics of TSL under scenarios with and without Sambor Dam were analyzed for one typical dry and wet year. The results show that if the dam is installed, the extent of hydrological variation in TSL will decrease. Especially, minimum water level would increase 1.2m in dry season and peak flood water level would decrease by 1.0m. This paper is only focused on the potential influence of hydrological interacting variables on TSL and the Mekong River by Sambor Dam, the impact of ecosystem and fish production

of TSL need to be further discussed. Integration of RLWE model with basin-scale hydrological model would also be in the future work for the impact analysis of other potential human activities on hydrological cycle in this region.

REFERENCES

1) Bonheur, N. : Tonle Sap Ecosystem and Value. Technical Coordination Unit for Tonle Sap, Ministry of Environment, Phnom Penh, Cambodia, 2001.
2) Keskinen, M. : The lake with floating villages: socio-economic analysis of the Tonle Sap Lake, *Int. J. Water Resource.,* Dev. 22, pp. 463–480, 2006.
3) Kummu, M. and Nikula, J. : Ecosystem management of Tonle Sap Lake: An integrated modelling approach. *Int. J. Water Resource.,* Vol. 22, pp.497–519, 2006.
4) Sverdrup-Jensen, S. : Fisheries in the Lower Mekong Basin: Status and perspectives. *MRC Technical Paper* No. 6. Mekong River Commission, 2002.
5) Kummu, M. and Sarkkula, K. : Impact of the Mekong River Flow Alteration on the Tonle Sap Flood Pulse, *J. Royal Swedish Academy of Sciences,* pp. 185-192, 2008.
6) Sambor dam, Kratie province, Cambodia, Bangkok, *TERRA*., September 2007.
7) Background to the Mekong mainstream dams, Bangkok, *TERRA*., September 2007.
8) Press Briefing: MRC silent as mainstream dams move forward, Bangkok, *TERRA*., 8 November 2007.
9) Acres International Limited and Compaigne Nationale du Rhone, Mekong Mainstream Run-of-River Hydropower, Mekong Secretariat, Bangkok, 1994.
10) Chan, S., Putrea, S., Sean, K., and Hortle, K.G. : Using local knowledge to inventory deep pools, important fish habitats in Cambodia, *Proceedings of the 6th Technical Symposium on Mekong Fisheries,* pp.65, 2003.
11) López, R. and Barragán, J. : Flow resistance equations without explicit estimation of the resistance coefficient for coarse-grained rivers, *J. Journal of Hydrology,* Vol. 338, Issues 1-2, pp. 113-121, 2007.
12) Inomata, H. and Fukami, K. : Restoration of historical data of Tonle Sap Lake and its surrounding areas, *J. Hydrological Processes,* 22, pp.1337-1350, 2008.
13) Mekong River Commission: Lower Mekong Hydrologic Yearbook, 1970.
14) Rajput, R.K. : *A Textbook of Power Plant Engineering*, pp.585, 2005.
15) Gevorkian, P. : *Sustainable energy systems engineering: the complete green building design resource,* pp.313, 2006.
16) Lamberts, D. : Little impact, much damage: The consequences of Mekong River flow alterations for the Tonle Sap ecosystem. *Modern Myths of the Mekong*, pp. 3–18, 2008.
17) Zalinge, N.P. : Mekong fisheries network newsletter, *Mekong Fish Catch and Culture*, Vol.8, No.2, 2002.