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Stream Temperature Analysis in Nam Ngum River Basin,Mekong

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Water temperature affects nearly every physical property of concern in water quality management and, unfortunately, the change of water temperature is often associated with undesirable. Control of water temperature therefore becomes a prerequisite for maximum utilization of water resources. Reservoirs often provide a means for exercising such controls. In this study, to evaluate artificial effect to the downstream environment, changes in river water temperature by dam construction were estimated. Then mitigation effect by the adoption of surface intake on the dam site was examined.

Key Words : *Mekong, Runoff analysis, Stream Temperature, Dam Management*

1. Introduction

The Mekong is a large international river. It flows through 6 countries (China, Myanmar, Thailand, Laos, Cambodia, Vietnam) so that conflicts of water resource utilization often occur between upstream and downstream areas. After the establishment of the MRC (Mekong River Committee), dam construction in the main stream was prohibited. However many dam construction projects are planned in the tributaries, especially in Laos. Laos is blessed with good topographical condition for hydroelectric power sites and recently switched its economic policy from forest resources exportation to electric power exportation. Generally, dams for generating electricity have been regarded as non-consumptive water use (as opposed to dams for irrigation that are regarded as consumptive use), and at the same time fish ways are constructed to compensate for the cutting off upstream and downstream habitats. In view of water volume, electric dams are regarded as non-consumptive use, and thus fish ways have been regarded as successfully satisfying ecological needs as a connection between the upstream and downstream habitats.

However, how about heat environmental change in the downstream? Temperature is perhaps important parameter in stream-water quality. Human activity raises or declines natural stream-water temperature due to impoundments, industrial uses, irrigation and global warming (**Bartholow 1989**[1], **LeBlanc 1997**[2]). Water temperature affects nearly every physical property of concern in water quality management and, unfortunately, the change of water temperature is often associated with undesirable. Previously, stream temperature increases by solar energy (solar radiation, convection, conduction) under non-dam condition as flowing to downstream, and especially decreases by dam release cool water (**Delay 1966**[3], **Bashar 1993**[4]). Control of water temperature therefore becomes a prerequisite for maximum utilization of water resources. Reservoirs often provide a means for exercising such controls.

In this study, to evaluate artificial effect to the downstream environment, changes in river water temperature by dam construction were estimated. Then mitigation effect by the adoption of surface intake on the dam site was examined.

2. Study Area

In this study the Nam Ngum River basin was selected as study area. Nam Ngum river is a large tributary of the Mekong River, having a length of 420 km and drainage basin of 16,400 km^2. It flows through Vientiane (Capital) and has a big dam (Nam Ngum dam) shown in **Fig.1**. The Nam Ngum dam is located just upstream of the confluence of the Nam Ngum and Nam Lik rivers and has a 8,280 km^2 catchment area. Nam Ngum dam has a 75m height, 9×10^9 m^3 capacity and 30m depth (**Hori 2000**[5)]). In this study, discharge data from two gauge stations on the Nam Ngum River (Naluang, Pakkagnoug) and one gauge station (Hinheup) on the Nam Lik river were used. Stream temperature was evaluated for cases with and without a dam, surface intake case.

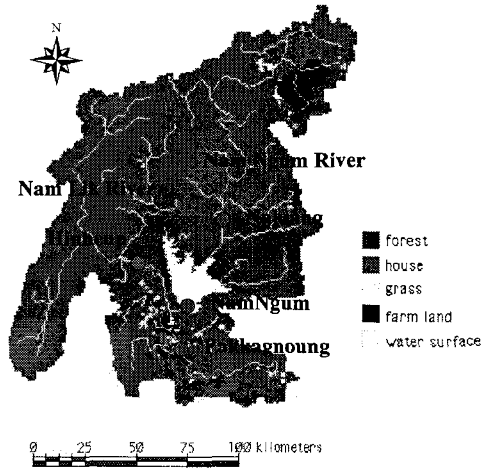

Fig.1 Nam Ngum River Basin

3. Data Set

In this study, topographic, hydrological, and meteorological data sets were used. Stream flow line, watershed area, hill slope, stream length were calculated (shown in **Table.1**) from the Global Map DEM data. Then the study area was modeled and schematized simply based on the calculated sub-basin (shown in **Fig.2**).

Item	**Source**
<u>Topography data</u>	
Digital Elevation Map	(Global Map)
Vegetation Map	(Global Map)
<u>Hydrology data</u>	
Precipitation	(Year Book 1997)
Water level, Discharge	(Year Book 1997)
Sediment concentration	(Year Book 1997)
<u>Meteorological data</u>	
Air temperature (monthly)	(Year Book 1997)
Wind speed (monthly)	(Year Book 1997)
Sunshine duration (monthly)	(Year Book 1997)
Humidity (monthly)	(Year Book 1997)

Table.1 Values calculated from DEM deta

	Naluang	Pakkagnoung	Hinhiup	NamNgum
Length (km)	205	304	153	269
Area (km^2)	5,220	14,300	5,115	8,280
Slope	0.0047	0.0005	0.0053	0.0036

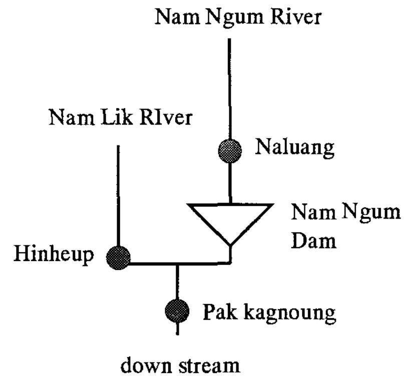

Fig.2 Schematized watershed

4. Runoff Analysis

In this study we employed a TOPMODEL to calculate the discharge at Pakkagnoug station in without dam condition. TOPMODEL was proposed by **Beven and Kirkdy (1979)**[6)] based on contributing area concept in hill slope hydrology (shown in **Fig.3**). This model is based on the exponential transmissivity assumption that leads to a topographic index ln$(a/To/\tan b)$. *To* is the lateral transmissivity under saturated conditions, and a is the upstream catchment area draining across a unit length, b is the local gradient of ground surface. This model has a combination of lumped and distributed characteristics using a topographic index, so many improved models have been applied to the Mekong river basin (**Ao 1999**[7)], **Nawarathna 2001**[8)]).

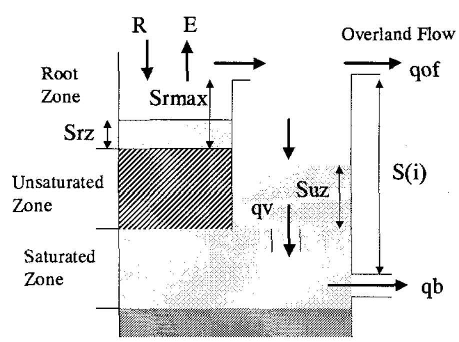

Fig.3 TOPMODEL structure

Discharge is composed of overland and base flow. Saturation deficit controls the discharge from local area. The local saturation deficit is determined from local topographic index relative to its average value λ. Thus, the topographic index is the critical controlling factor in runoff generation and is a function of topography and soil type.

Over a whole area, an average saturation deficit $S(t+1)$ is determined from Eq.(1).

$$S(t+1) = S(t) - Qv(t) + Qb(t) \qquad (1)$$

where, $S(t)$ is previous average saturation defict, $Qv(t)$ is infiltration to groundwater from unsaturated zone, $Qb(t)$ is base flow discharge from groundwater to stream over all grids.

The average saturation deficit $D(t)$ is distributed to local saturation deficit $S(i,t)$ at grid cell i, according to the magnitude of local topographic index relative to its average λ as follows.

$$S(i,t) = D(t) + m \times (\lambda - \ln(a / To / \tan b)) \qquad (2)$$

where, m is the decay factor of lateral transmissivity with respect to saturation deficit in meters.

Rainfall on the i grid cell is first inputted to the root zone. The storage in the root zone $Srz(i,t)$ changes as follows,

$$Srz(i,t) = Srz(i,t-1) + R(i,t) - E(i,t) \qquad (3)$$

where, R is precipitation and E is evapotranspiration.

The excess of root zone storage $Srz(i,t)$ is inputted to the unsaturated zone and its storage $Suz(i,t)$ is calculated by Eq.(4).

$$Suz(i,t) = Suz(i,t-1) + Srz(i,t) - Srz\,max(i,t) \qquad (4)$$

where, Srmax is maximum height of root zone tank.

Overland flow from grid cell i, qof(i,t) can be estimated as follows,

$$qof(i,t) = Suz(i,t) - S(i,t) \qquad (5)$$

Groundwater discharge is considered semi-steady depending on the saturation deficit. The hydraulic gradient is assumed parallel to the ground surface. Groundwater discharge from grid cell i is determined from Eq.(6).

$$qb(i,t) = To \cdot \exp(-S(i,t)/m) \cdot \tan b \qquad (6)$$

The discharge from grid cell i to the stream is the summation of $qof(i,t)$ and $qb(i,t)$.

TOPMODEL mentioned above, was applied to Nam Ngum river basin and Kinematic wave method was employed for flow routing along the main stream. **Fig.4** and **Fig.5** shows results of model calibration at the Naluang station and the Hinheup station respectively.

In this study we employed a simple assumption that inflow discharge to Num Ngum dam can be estimated by specific discharge ($m^3/s/km^2$) from Naluang station discharge, and inflow discharge to Nam Ngum Dam + Hinheup discharge can be regarded as Pakkagnoug discharge in Non-dam condition. And with-dam case, water level-capacity relation from hysterical records was used for calculating dam release discharge (**Fig.6**).

Fig.7 shows calculated hydrograph in 1997 at the Pakkagnoung station in each case of with and without a dam. In the with dam case, base flow in dry season increase and flood peak in rainy season is cut. In assessment based on water volume, this indicates improvement of water utilization by dam construction.

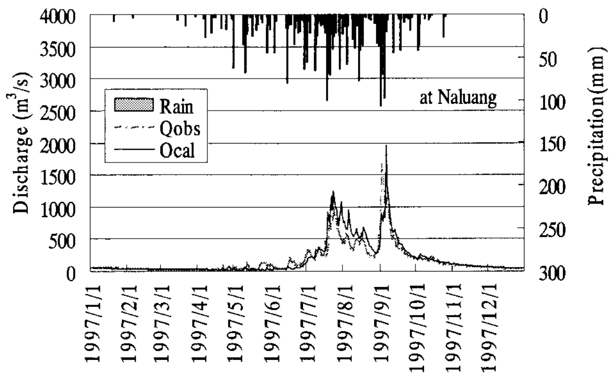

Fig.4 Hydrograph at Naluang

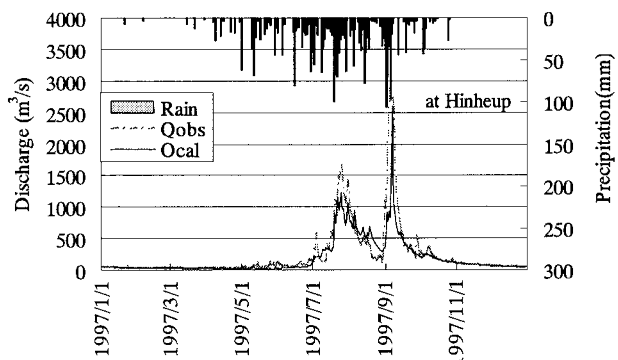

Fig.5 Hydrograph at Hinheup

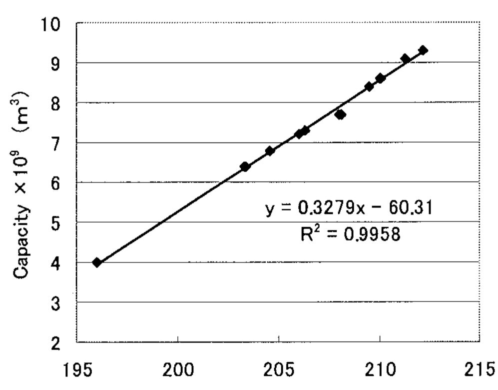

Fig.6 Relation of dam level-capacity

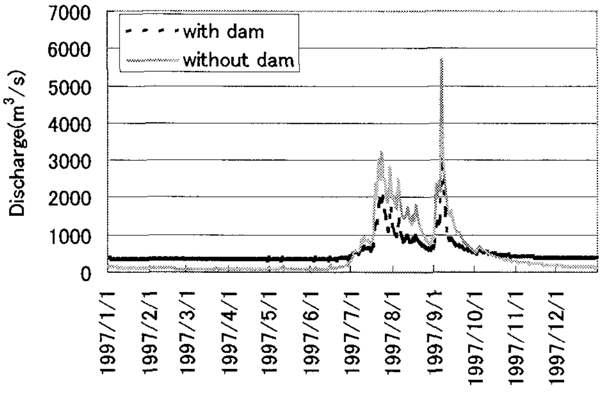

Fig.7 Discharge change of cases with and without a dam at Pakkagnoung Station

5. Stream Temperature Analysis

In this study, SSTEMP (Stream Segment Temperature Model, **Bartholow 1989**[1]) was employed for calculating stream temperature changes. SSTEMP solves the one-dimentional heat advection-dispersion equation and includes the heat exchange with the atmosphere. When applied to an open channel of constant cross section and flow, the heat transport equation takes the form

$$A\frac{\partial T}{\partial t}+\frac{\partial(QT)}{\partial x}=\frac{\partial}{\partial x}\left(AD_L\frac{\partial T}{\partial x}\right)+\frac{WS}{\rho C_p} \qquad (7)$$

where T is water temperature, x is distance, t is time, D_L is a dispersion coefficient in x direction, S is a source or sink term which includes heat transfer with the surrounding environment, A is cross sectional area, W is surface width, Q is flow rate. For numerical test, dispersion DL of 15-200 m2/s were applied, but increases of did not change model simulation results because of the relatively high velocity of flow and the low longitudinal temperature gradient along the modeled stream, indicating that the system was advection dominant. Therefore DL was set equal to zero in the model. Equation(7) can be used to predict water temperatures in steady flow streams that are well mixed and have no significant transverse temperature gradients, the main variation is in the flow direction. Stream cross sectional area A and width W are a function of stream flow rate Q, ρ is the density of water, and C_p is the specific heat of water.

The source or sink term S expresses the heat transfer rate with the surrounding environment:

$$S=S_a+S_b \qquad (8)$$

with

$$S_a=H_s-H_l-H_e-H_c \qquad (9)$$

where S_a is the net heat exchange rate between the water and the air, S_b is the net heat exchange between the water and the streambed, H_s is the net short-wave (solar) radiation, H_l is the net long-wave radiation, H_e is the evaporative heat transfer, H_c is the convective heat transfer

In general terms, SSTEMP calculates the heat gained or lost from a parcel of water as it passes through a stream segment. This is accomplished by simulating the various heat flux processes that determine that temperature change. These physical processes include convection, conduction, evaporation, as well as long wave radiation (heat to or from the air), direct solar radiation (short wave), and radiation back from the water. First, solar radiation and interception by shading are calculated. To calculate solar radiation, SSTEMP computes the radiation at the outer edge of the earth's atmosphere. This radiation is passed through the attenuating effects of the atmosphere and finally reflects off the water surface depending on the angle of the sun. Next sunrise and sunset time are computed by factoring in local east and west side topography. Thus the local topography results in a percentage decrease in the level plain daylight hours. From this local sunrise/sunset, SSTEMP compute the percentage of light that is filtered out by the vegetation.

SSTEMP requires inputs describing the average stream geometry, as well as (steady-state) hydrology and meteorology, and stream shading. SSTEMP optionally estimates the combined topographic and vegetative shade as well as solar radiation penetrating the water. Vegetation data was estimated using Global Map Vegetation data along the stream (shown in **Fig.8**). The model then predicts the mean daily water temperatures at specified distances downstream. It also estimates the daily maximum and minimum temperatures.

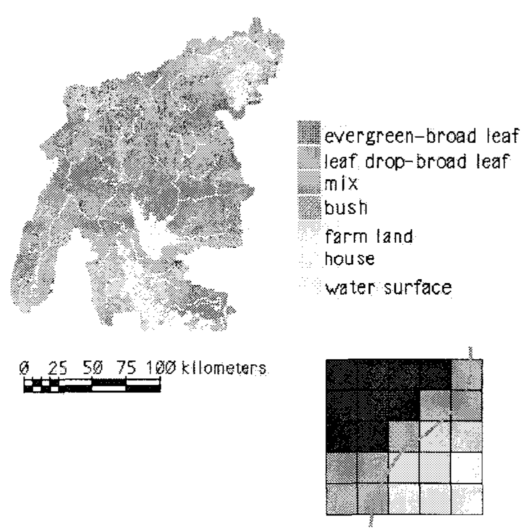

Fig.8 Vegetation shade along the stream

To apply the model, the Nam Ngum river basin was schematized (**Fig.2**) and three cases of analysis were conducted : with a dam, without one, and surface intake case. Nam Ngum dam release about 300m^3/s discharge for electricity and release water temperature is about 23℃(**Hori 2000**[5)]). In surface intake case, we estimated that 20% of 300 m^3/s were taken from the surface of reservoir[9)].

Fig.9 shows result of mean stream temperature change at Pakkagnoung in 1997. **In Fig.9**, the added vertical axis on the right shows discharge of Pakkagnoung in each case. If river condition is natural stream (in without dam case), Stream temperature greatly affected by air mean temperature. However how about the with dam case? In the dry season(Jan-June), total discharge is small so that the percentage of dam release discharge, which usually has a low temperature, increase. Thus stream temperature in the with dam case is about 5 ℃ cooler than in the without a dam case. In the rainy season (July-Oct), total discharge was so large that stream temperature was not so sensitive to dam-released cool discharge. Thus stream temperature is not so different between the two cases in the flood period (beginning of September). Even in the rainy season, however, stream temperature decrease under with-dam condition when the percentage of dam-released cool discharge increased. In the surface intake case, stream temperature is about 2℃ warmer than with-dam case. Ecological knowledge leads appropriate stream temperature and we can manage the river for required condition by adoption of surface intake.

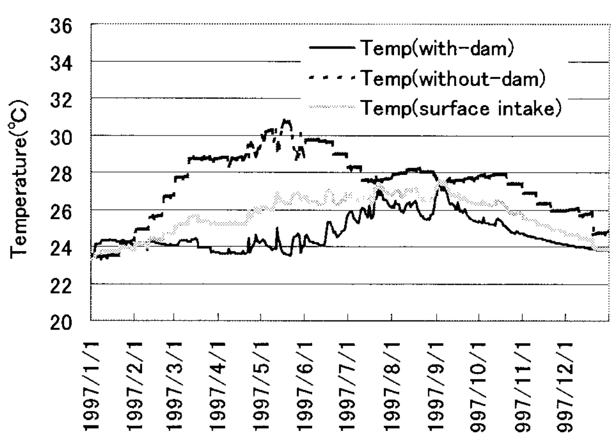

Fig.9 Stream temperature change in the cases of with and without a dam, surface intake

6. Conclusion

In this study we examined stream temperature change by dam release water management. To assess dams in detail, not only water volume but also water temperature should be considered. Stream temperature is an especially important parameter to evaluate any artificially induced impact on the environment and ecosystem. The results shows that dam construction makes stream temperature cooler and it can be controlled by appropriate surface intakes from the reservoir. Dam management affects downstream environment strongly, so more detail monitoring are essential to estimate the impact of artificial activity and now under measuring in the field from this June 2003. In this study, an open source, steady-state model (SSTEMP) was applied directly to discharge data to calculate stream temperature change. For further improvement, therefore surface flow and temperature should be solved dynamically at the same time in the physical process.

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