The Management of Stream Temperature in Laos

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ABSTRACT

The Mekong River is a large international river that flows through six countries, so conflicts concerning the use of water resources often occur between upstream and downstream areas. After the establishment of the 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 conditions for hydroelectric power sites and recently switched its economic policy from exporting forest resources to exporting electric power. It is therefore particularly important to assess the development and operation of dams.

This paper evaluates changes in stream temperature and soil sediment by managing the release of dam water in the Nam Ngum river basin. A stream temperature calculation model was developed to evaluate the change in temperature of the environment that seriously affects the habitat of fish. A solution for balancing dam management with environmental protection in this area is suggested.

Key words : Mekong , dam assessment, energy,water temperature, soil sediment

1. INTRODUCTION

The Mekong River is a large international river that flows through six countries (China, Myanmar, Thailand, Laos, Cambodia, Vietnam), so conflicts concerning the use of water resources often occur between upstream and downstream areas. After the establishment of the Mekong River Committee (MRC), 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 conditions for hydroelectric power sites and recently switched its economic policy from exporting forest resources to exporting electric power. 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 fish ways are constructed to compensate for the cutting off of upstream and downstream habitats. In view of water volume, hydroelectric dams are regarded as non-consumptive use, and thus fish ways that connect upstream and downstream habitats have been regarded as satisfying ecological needs. However, how about energy (such as potential, momentum, heat or friction)? Potential energy must be consumed for the generation of hydroelectric power. This paper proposes a concept of dam assessment based on the energy of river water. The authors estimated the change of energy based on the stream temperature and soil sedimentation for the two cases of with and without dams. These two components are important parameters for the downstream habitat.

1) Stream temperature is affected by urbanization, water withdrawal for agriculture, hypolimnetic releases from hydropower facilities and global warming (**Bartholow 1989**, **LeBlanc 1997**). Stream temperature usually increases by solar energy (solar radiation, convection, conduction) under the without-dam condition as it flows downstream. Changes in river water temperature by dam construction were estimated in order to evaluate their impact on the heat energy of stream flow.2) The potential energy of river water must be converted into friction stress to erode the riverbed under the without-dam condition. The change of soil erosion by dam construction was estimated in order to evaluate the impact of soil supply on the downstream area. Soil is an important medium that transports nutritive salts and so the amount of soil supply must be considered when assessing downstream ecological systems.

2. STUDY AREA

The Nam Ngum river basin was selected as the study area. The Nam Ngum River is a large tributary of the Mekong River, with a length of 420 km and drainage basin of 16,400 km^2. It flows through Vientiane (shown in **Fig. 1**) and has a large dam (Nam Ngum dam) as shown in **Fig. 2**. The Nam Ngum dam is located just upstream of the confluence of the Nam Ngum and Nam Lik Rivers and has a catchment area of 8,280 km^2. 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 the two cases of with and without a dam.

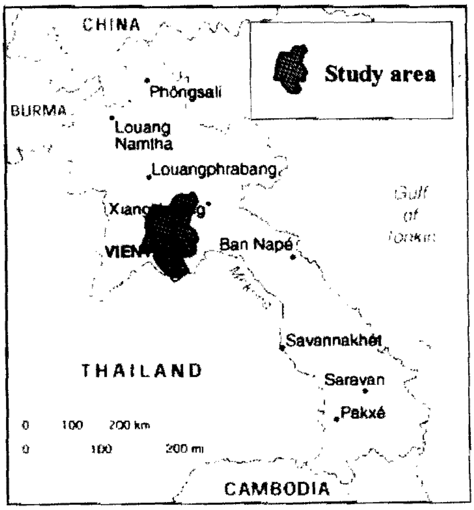

Fig. 1 Location of study area

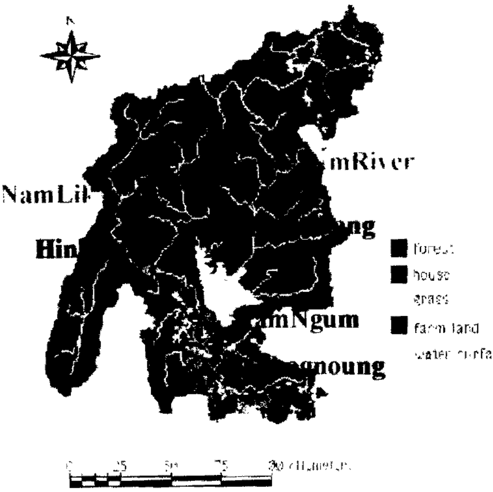

Fig. 2 Nam Ngum river basin

3. DATA SET

In this study, topographic, hydrological, and meteorological data sets were used. Stream flow line, watershed area, hill slope, and stream length were calculated (shown in **Table 1**) from the Global Map DEM data (**Fig. 3**). Then the study area was modeled and schematically analyzed based on the calculated sub-basin (shown in **Fig. 4**).

Item	Source
Topography data	
Digital Elevation Map	(Global Map)
Vegetation Map	(Global Map)
Hydrology data	
Precipitation	(Lower Mekong Hydrologic Year Book 1997)
Water level, Discharge	(Lower Mekong Hydrologic Year Book 1997)
Sediment concentration	(Lower Mekong Hydrologic Year Book 1997)
Meteorological data	
Air temperature (monthly)	(Lower Mekong Hydrologic Year Book 1997)
Wind speed (monthly)	(Lower Mekong Hydrologic Year Book 1997)
Sunshine duration (monthly)	(Lower Mekong Hydrologic Year Book 1997)
Humidity (monthly)	(Lower Mekong Hydrologic Year Book 1997)

Table 1 Values calculated from DEM data

	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

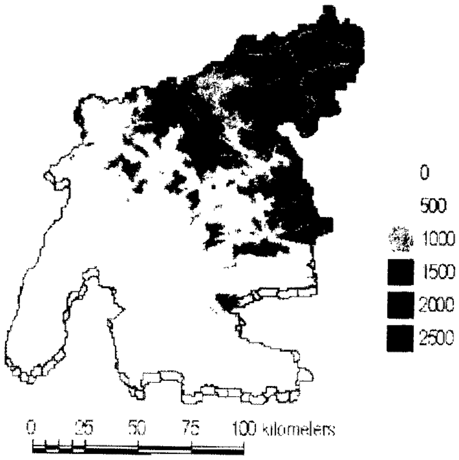

Fig. 3 Global Map DEM data

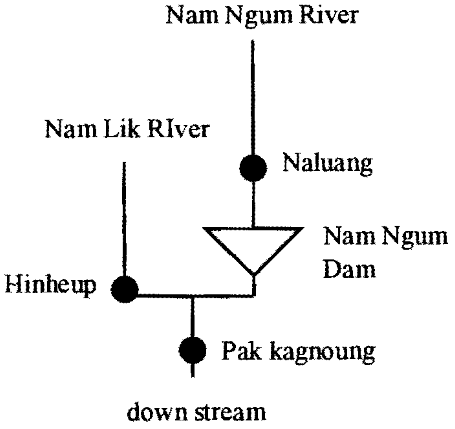

Fig. 4 Schematic diagram of watershed

4. RUNOFF ANALYSIS

In this study we employed a TOPMODEL to calculate the discharge at Pakkagnoug station in the without-dam condition. TOPMODEL was proposed by **Beven and Kirkdy (1979)** based on the concept of contributing area in hill slope hydrology (shown in **Fig. 5**). This model is based on the exponential transmissivity assumption that leads to a topographic index ln(a/To/tanb), where To is the lateral transmissivity under saturated conditions, a is the upstream catchment area draining across a unit length, and b is the local gradient of the 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 (Nawarathna, 2001).

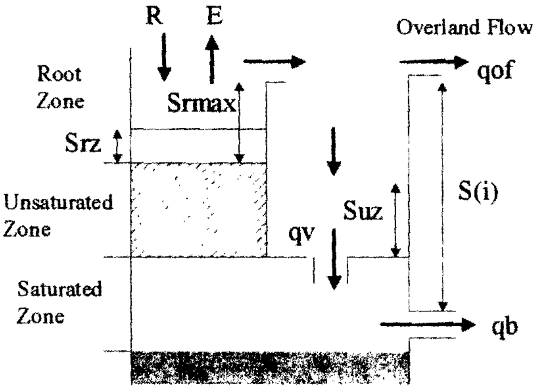

Fig. 5 TOPMODEL structure

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

Over a whole area, an average saturation deficit S(t+1) is calculated by

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

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

The average saturation deficit S(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:

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

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

Rainfall on grid cell i 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

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

where, Srmax is maximum height of root zone tank.

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

$$qof(i,t) = Suz(i,t) - S(i,t) \tag{5}$$

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

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

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

The TOPMODEL mentioned above was applied to the Nam Ngum river basin. **Figures 6** and **7** show the 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 the 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 + Hinhiup discharge can be regarded as the Pakkagnoug discharge in the without-dam condition.

Figure 8 shows a hydrograph in 1997 at the Pakkagnoung station in each of the cases of with and without a dam. In the with-dam case, the base flow in the dry season increases and the flood peak in the rainy season is reduced. In the assessment based on water volume, this indicates that water utilization is improved by dam construction.

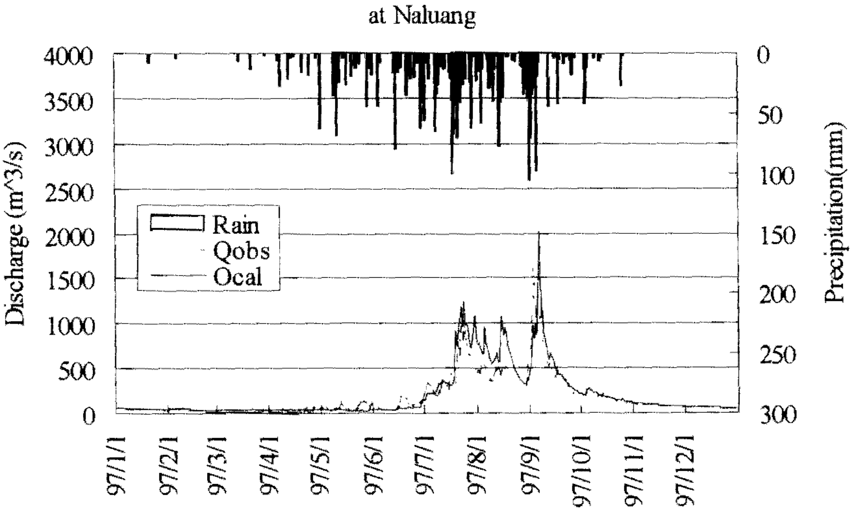

Fig. 6 Hydrograph at Naluang

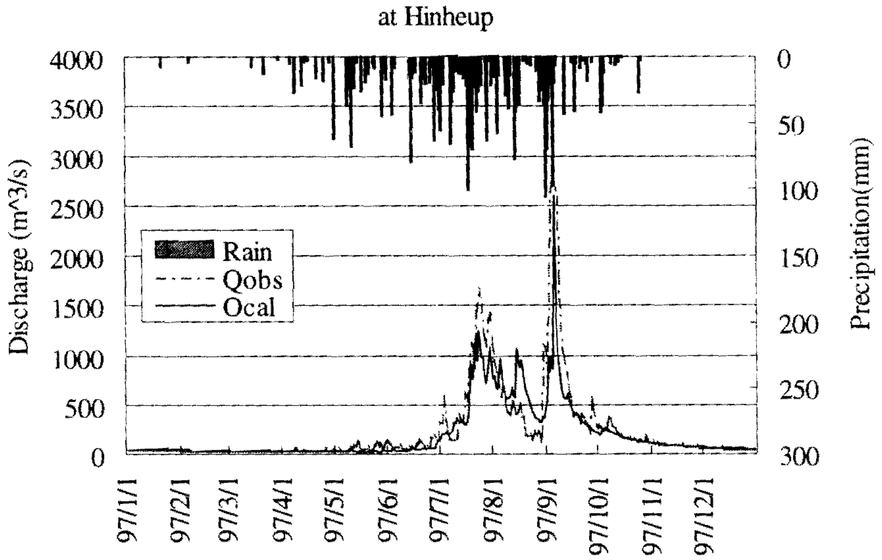

Fig. 7 Hydrograph at Hinheup

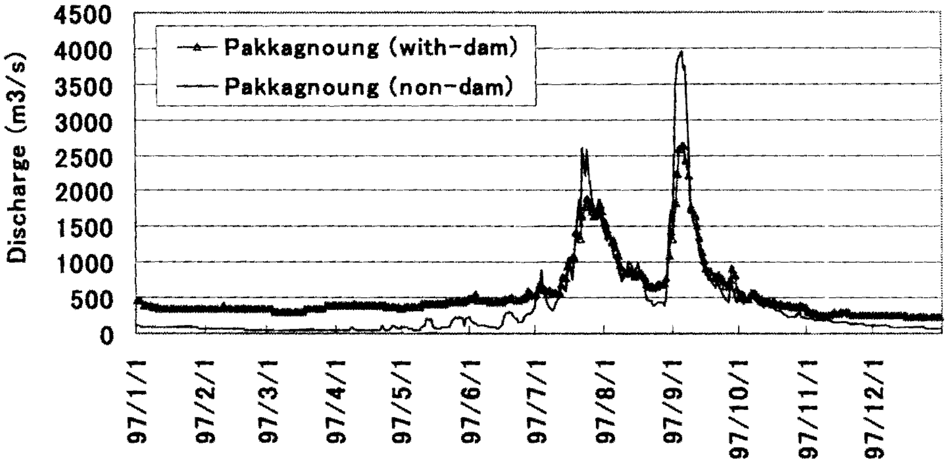

Fig. 8 Discharge change of cases with and without a dam

5. STREAM TEMPERATURE ANALYSIS

In this study, SSTEMP (Stream Segment Temperature Model, **Bartholow 1989**) was employed for calculating stream temperature changes. To apply the model, the Nam Ngum river basin was drawn schematically (**Fig. 4**) and two cases of analysis were conducted: with a dam, and without one.

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 affect the temperature. 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 computes 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. The model then predicts the mean daily water temperatures at specified distances downstream. It also estimates the daily maximum and minimum temperatures.

Figure 10 shows the mean stream temperature change in case (a) with dam and case (b) without dam at Pakkagnoung in 1997. In **Fig. 10**, the added vertical axis on the right shows the discharge of Pakkagnoung in each case. If the river condition is a natural stream (in the without-dam case), the stream temperature is greatly affected by mean air temperature. In the with-dam case, in the dry season the total discharge is small and so the percentage of dam release discharge, which usually has a low temperature, increases. Thus, the stream temperature in the with-dam case is about 5°C cooler than in the without-dam case. In the rainy season, the total discharge was so large that stream temperature was not so sensitive to dam-released cool discharge. Thus, stream temperature varies little between the two cases in the flood period (beginning of September). Even in the rainy season, however, stream temperature decreases in the with-dam condition when the percentage of dam-released cool discharge increases. These results indicate that the total amount of heat energy/year at downstream Pakkagnoung decreases, especially in the dry season.

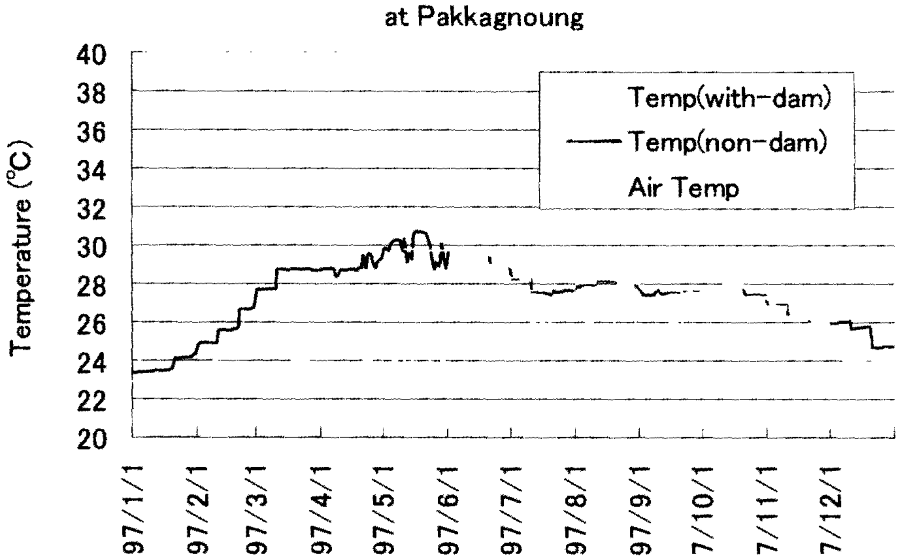

Fig. 10 Stream temperature change for the two cases of with and without a dam

6. SOIL SEDIMENTATION ANALYSIS

It is well known that dams interrupt sedimentation flow, especially bed load flow. When there is no dam, stream flow erodes the riverbed by friction. When there is a dam, however, dams store such friction energy and generate hydroelectricity. To assess the effects of a dam in detail, the change in soil sedimentation should be considered along with stream temperature, because potential energy loss by friction stress increases water temperature. In this study, soil sedimentation was calculated by the L-Q equation, using data obtained from gauging stations, and assuming steady-state analysis. **Figure 11** shows the relation between load and discharge at each gauging station. Sediment at Pakkagnoung in the with-dam case was calculated by the original L-Q equation and Naluang + Hinheup sedimentation was assumed as the sediment at Pakkagnoung in the without-dam case.

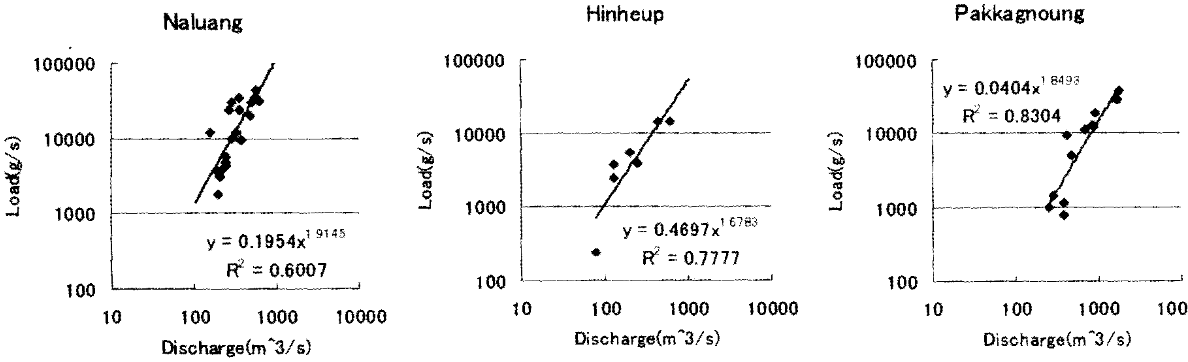

Fig. 11 L-Q relation at each gauging station

Figure 12 shows calculated values for soil sediment at downstream Pakkagnoung. Soil erosion occurs with energy slope and so is predominant in the rainy/flood season. Due to the discharge peak reduction effect of dams, however, soil sedimentation decreases in the rainy season in the with-dam case. The momentum energy of fluid is converted to momentum energy of soil sediment by erosion, and so in the total amount/year, friction energy is approximately halved due to dam construction.

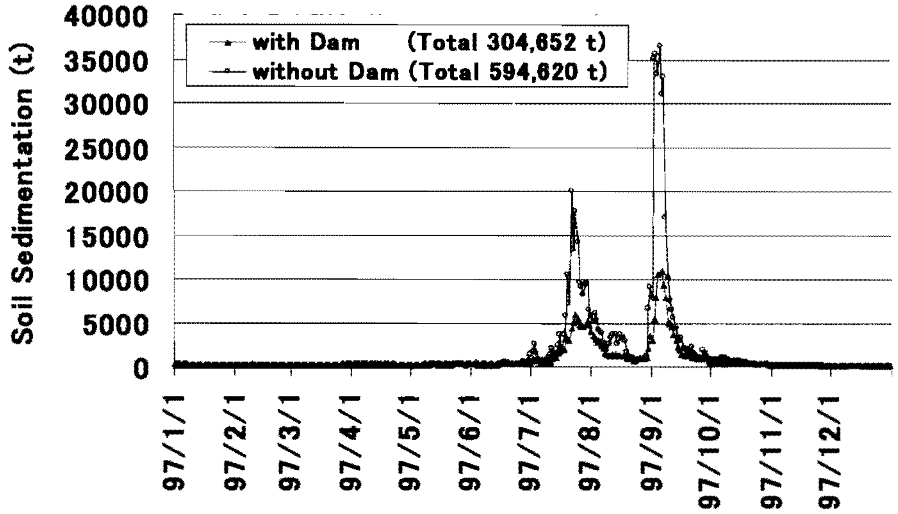

Fig. 12 Soil sedimentation change for the two cases of with and without a dam

7. CONCLUSION

In this study we examined energy change based on stream temperature or soil sedimentation. To assess dams in detail, not only water volume but also water energy should be considered. Stream temperature is an especially important parameter to evaluate any artificially induced impact on the environment and ecosystem. Soil management is also important for the downstream habitats, because soil sediment transfers nutritive salts such as nitrogen and phosphorus. Dam management greatly affects these two parameters, so stream temperature and soil sediment analysis and monitoring are essential in order to estimate the impact of artificial activity. In this study, an open source, steady-state model (SSTEMP) was applied directly to discharge data to calculate changes in stream temperature. In our soil sedimentation analysis, we also assumed the steady-state and used the empirical L-Q equation. For further improvement, the surface flow, temperature, and sediment should be solved at the same time in the physical process.

ACKNOWLEDGEMENT

This research was partially supported by two Grant-in-Aids: Revolutionary Researches 2002 of the Ministry of Education, Science, Sports and Culture, and CREST of Japan Science and Technology Corporation.

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