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Water Resources and Environment Assessment in River Basin based on Hydro-BEAM

Shuichi IKEBUCHI, Toshiharu KOJIRI, Yoshimi HAGIWARA,
Kunio TOMOSUGI, Yasuhiro TAKEMON, Kenji TANAKA
and Toshio HAMAGUCHI

Synopsis

In this fiscal year (FY2005), some modules to be added to Hydro-BEAM and some aspects of evaluation have been discussed. Following items are the main topics and included in this report.

1) Regional water circulation processes with water quantity, quality, and ecosystem
2) Difference in habitat preference of Rhinogobius flumineus among erosional and depositional reaches
3) Variation in drift distance of suspended POM in relation to flow regimes and channel geomorphology
4) Effect of land surface condition on convective precipitation over the mountainous region in Lake Biwa during the summer season
5) Impact assessment on water resources environment in river basin due to global warming

Keywords: Hydro-BEAM, Impact Assessment, land cover, ecosystem, global warming

1. Introduction

The Water Resources Research Center is promoting research activities aiming at the understanding and prediction of river basin water and substance dynamics coupled with atmospheric phenomena and the creation of community-based hazard map.

The basic concept of this research program is to figure out the variation and transport of water quantity, water quality, and sediment within watershed and river channel through in-situ observation, data analysis, and modeling and to develop the river basin environment assessment model through comprehensive simulation including the control of water quantity, water quality, and sediment such as reservoir operation for assessing their risk.

As shows the framework of the assessment system based on numerical model and simulation, Hydro-BEAM is a basic component for water quantity and quality.

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2. Regional water circulation processes with water quantity, quality and ecosystem

2.1 River basin simulation with distributed runoff model

The river basin is modeled with multi-mesh and multi-layer-typed runoff model combined with GIS data. As the whole river basin must be considered, the basic mesh consists of squares and only one and straight channel exists in a mesh according to the digital elevation map. The mountain, paddy field, urbanized zones are decided with their occupation ratios under the classified infiltration rate. Regarding to the paddy field, the intake discharge volume from river, the distribution procedures and storage (or overflow) process are formulated through the linear storage method concept. Secondly, the concentrations of water qualities in the river channel are calculated through diffusion and emission processes. As the water temperature is also one of the most important factors for creatures in rivers, it is analyzed by considering the heat balance of air temperature, soil temperature and heat conductivity between atmosphere, groundwater and soil in the ground. Finally, the impact of global warming on water resources is estimated under the assumption of global warming scenarios.

Fig. 1 shows the proposed mesh-typed multi-layer runoff model in river basin. For water quantity, the heat balance method is introduced to calculate the evaporation and snowmelt at each mesh and at each day. On the runoff process, the runoff model is applied with the kinematic wave method for surface and the linear storage method for ground water of first to forth layer.[Kojiri, T. and Kobayashi, M.2003]

For water quality, the water temperature and water pollutant are analyzed from an environmental viewpoint. The water quality is assumed that the sewerage water from the factories or houses flows down into the river through individual treatment tank, combined treatment tank, or sewerage network for agriculture. The inflow concentration of waste water to the river is calculated according to pollutant load per unit activity. The waste water from non-point source is also obtained through weighted mean interpolation at each land use as follows;

$$L_{np} = \frac{\sum L_{npu} A_u}{A} \quad (1)$$

where, L_{npu} is the released load unit of non-point pollutant for land use u (mg/m^2/day), A_u is area of land use u (m^2). The traction load of piled material from non-point source is represented in proportion to the square of runoff height as follows;

$$L_{swp} = k_{wnp} P_{np} Q_h{}^2 A \quad (2)$$

where, Q_h is horizontal runoff height (m/h), k_{wnp} is traction coefficient due to non-point source (h/m^2), P_{np} piled pollutant load (mg/m^2) [T. Kunimatsu and K. Muraoka, 1990]. The outflow and inflow load (mg/h) are formulated as follows;

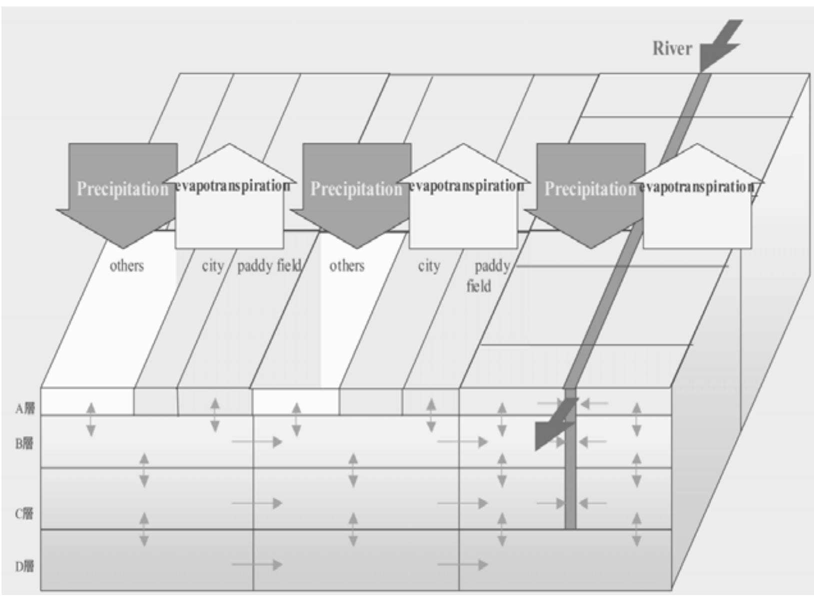

Fig. 1 Schematic illustration of mesh-typed multi-layer runoff model.

- outflow load - $L_{vout} = \sum C_{vi} Q_{out} A$ (3)

- inflow load - $L_{viin} = \sum \left(C_w Q_{in} A + L_{swpw} \right)$ (4)

where, C_v is concentration at control volume v (mg/m^3). The piling, traction, infiltration, accumulation and leaching processes are represented in the reference.

2.2 Impact assessment on aquatic biota population

To evaluate the environment quality, the population of aquatic biota (for example, fish) is employed as the impact on ecosystem because the fish represented as one of typical species is influenced in his body through water quality. Herein Physiology based Pharmacokinetic model can be applicable to simulate the affected processes as compartment model expressed in Fig.2, such as taking process of the dissolved chemicals into the fish body through gill, taking process of the absorbed suspended materials as food and chemical dynamics between the internal organs.[Nichols, J.W., et al., 1990] The chemical balance in the internal organs is represented as follows;

$$V_{organ} \frac{dM_{organ}}{dt} = G_{organ}^{in} \left(M_{organ}^{in} - M_{organ} \right) - \xi_{organ} M_{organ} V_{organ} \quad (5)$$

where, V_{organ} is capacity of organ, M_{organ} is chemical concentration in organ, $G^{in}{}_{organ}$ is the blood inflow into organ, $M^{in}{}_{organ}$ is chemical concentration in organ, ξ_{organ} is decomposition velocity for chemicals in organ. Consequently, the population of fish is estimated using the logistic curve concept through the following equation;

$$\frac{dN_i}{dt} = \gamma N_i - \frac{\gamma}{\chi} N_i^2 - u\left(M_{organ}^{i} - M_{organ}^{i,threshold} \right) N_i \quad (6)$$

where N_i is total population of considered aquatic biota at growth level i, γ is natural increase rate of population, χ is environmental capacity, u is coefficient of extinction velocity, $M^{i,threshold}{}_{organ}$ is threshold value. The environment index is defined as integration of all impacts according to the growth levels of biota. The impact of population change with and without case of chemical exposure is represented as follows;

$$R_i = \frac{N_i^{with}}{N_i^{without}} \quad (7)$$

$N^{with}{}_i$ is the population of aquatic creature with exposed chemical at growth level i and $N^{without}{}_i$ is the population of creature without exposed chemical. Then the recreation potential of population can be calculated through the following multiplication;

$$\Delta R = \Pi R_i \quad (8)$$

where, R_i is population level impact in each life stage i. The above parameters are presently not sufficient to show all ecological conditions, because their values are decided through not eco-toxicology but ichthyology aspect.

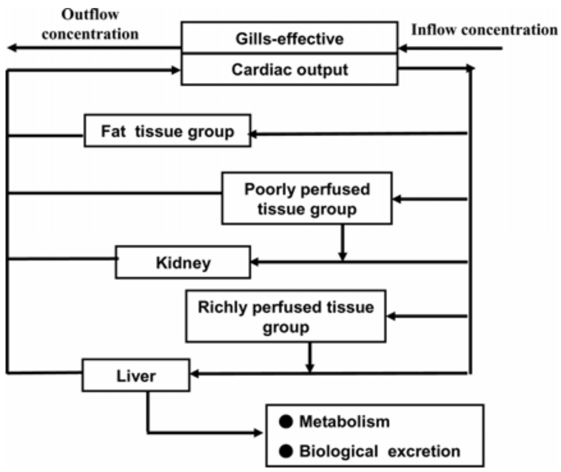

Fig. 2 Conceptual description of PBPK model.

3. Difference in habitat preference of Rhinogobius flumineus among Erosional and Depositional reaches

When we evaluate habitat conditions in stream ecosystems, it is beneficial to examine the hierarchical structure of riverbed geomorphology in relation to erosion-deposition process of sediment. In this study, habitat preference of freshwater goby, Rhinogobius flumineus was investigated in erosional and depositional reaches in Kamo River, Kyoto, Japan in early summer (Jun: low flow), summer (Jul-Aug: low flow) and autumn (Oct-Nov: high flow) 2004. Reaches of the study area were classified into three types: i.e., depositional reaches of a sediment control dam characterized by depositional features with low hydraulic gradient, erosional reaches without dam effects on stream geomorphology, and transitional reaches with intermediate amount of sedimentation along the channel. Distribution of adult and young fish was individually plotted on the riverbed maps in each reach. Habitat suitability indices for the depth, water velocity, and substrate were calculated for adult and young fish separately in each reach type. Under low flow conditions in early summer and summer, preference of adult fish in the depositional and transitional reaches were separated in two groups, i.e., cobble of riffle and bedrock of pool. Matured male in early summer exclusively nested at cobble bed in the shallow area located at itpool tail and riffle head.ld On the other hand, young fish preferred pebble and cobble beds in riffles. However, both adult and young fish in the erosional reach inhabited on cobble bed in riffle. Under high flow condition in autumn, both adult and young fish moved away from the erosional reaches to the depositional and transitional reaches, and preferred cobble and pebble beds in pools. They lived in the depositional and the transitional reaches in all seasons.

These results showed that habitat preference of Rhinogobius flumineus changed corresponding not only to growth stage but also to erosional-depositional habitat conditions and to flow regimes. Utilization of cobble bed in riffles in transitional reaches as spawning sites might be explained by higher velocity of hyporheic waters which brought more DO to eggs under nest stones.[Y. Ishida, Y. Takemon, T. Tanaka, H. Yamada, and S. Ikebuchi, 2005]

4. Variation in Drift distance of SUSPENDED POM in relation to flow regimes and channel geomorphology

The length of nutrient spiraling in river ecosystems is expected to be changed according to flow regimes and channel geomorphology. Its measurement, however, is not easily particularly in the field streams under different flow regimes. The present paper focuses on the drift distance of suspended particulate organic matter (SPOM) as an indicator of nutrient spiraling length and aims to show the variation in its drift distance between two rivers different in channel morphology under a set of different flow regimes.

Drift distance of SPOM was estimated using planktons as tracers in the downstream reaches of two reservoir dams, Takayama Dam in the Kizu River and Amagase Dam in the Uji River, central Japan. The Kizu River is characterized by shallow braided channels with a lot of sandy bars, whereas the Uji River by a single deep channel with few bars. We collected the SPOM samples using POM net from nine sites within 47km reaches from Takayama Dam in the Kizu River and from six sites within 16km from Amagase Dam in the Uji River under low and high flow condition.

Size and source composition SPOM was quantitatively surveyed using a binocular and we found that SPOM of a size range of 0.125-0.250 mm in diameter were suitable for counting planktons from reservoir dam with the other POM. The reducing patterns of plankton fraction in the samples could be explained by an exponential function to the distance from the dam site. The drift distance estimated as a distance required for 50% and 90% reduction of plankton was 1.3 km and 4.4 km in the Kizu River under a flow of 33.6t/sec, respectively. Contrastingly, the distance for 50% and 90% reduction of plankton was 5.3 km and 17.6 km in the Uji River under a flow of 130 t/sec, respectively. In addition, we obtained similar estimates of 4.1km and 13.4 km in the Uji River under even under an increased flow of 350t/sec.

The shorter drift distance in the Kizu River than the Uji River indicate that the SPOM will trapped in the river bed within a short distance in the braided channel with sandy bar structure. A possibility of the estimated drift distance as an indicator of the length of nutrient spiraling in a river ecosystem is discussed.[Y. Takemon, K. Yamamoto, and S. Ikebuchi, 2005]

5. The Effect of Land Surface Condition on Convective Precipitation over the Mountainous Region in Japan during the Summer Season

In this study, the effect of land cover on convective precipitation in mountainous region in Japan on 15th Aug. 2001, during the IOP of the Lake Biwa Project is investigated by numerical simulations. The ARPS, which has been developed by University of Oklahoma, coupled with a land surface process model SiBUC, which has been developed by Kyoto University, is used in this study.

Firstly, a numerical simulation with 1.5km horizontal spacing, which has actual land

cover, is carried out and it is called CASE1. Secondly, a numerical simulation with the same horizontal spacing, which has imaginary land cover (forest is changed into paddy field), is carried out and it is called CASE2.

In Fig.3, significant reduction of rainfall over the mountainous region around the Lake Biwa can be seen in simulation of CASE2. This may be explained that the buoyant stability over the mountainous area is lager in CASE2 than CASE1 because near surface potential temperature is smaller and precipitable water is also smaller over mountainous area in CASE2 than CASE1. This may be explained that surface heating and transportation of water vapor by local circulation induced by surface heating is smaller in CASE2 than CASE1.

It is, therefore, indicated that the difference of land surface condition, such as land cover, can affect the amount of rainfall over the mountainous region in Japan on summer sunny days.[K. Souma, K. Tanaka., E. Nakakita and S. Ikebuchi, 2005]

6. Impact Assessment on Water Resources Environment in River Basin due to Global Warming

6.1 Impact Assessment on Water Resources Environment in River Basin

In this research, we use Hydro-BEAM.The evaluation periods are from 1979 to 2000 and from 2079 up to 2100. We use CGCM2, which has been developed and improved by the Meteorological Agency. It is based on the SRES A2 scenario of IPCC. After modifying it, we use the GCM output to evaluate the influence of global warming on the water resource quantity in the river basin because it is extremely difficult to use it without modification. We evaluate these impacts by distributed modeling and then analyze each component such as the value of precipitation, the snowfall, etc. in recent years and in further ones.

6.2 Simulation results and consideration

A target area in this research is the Nagara River Basin where the simulation results show the changes in hydrological and environmental conditions as follows.

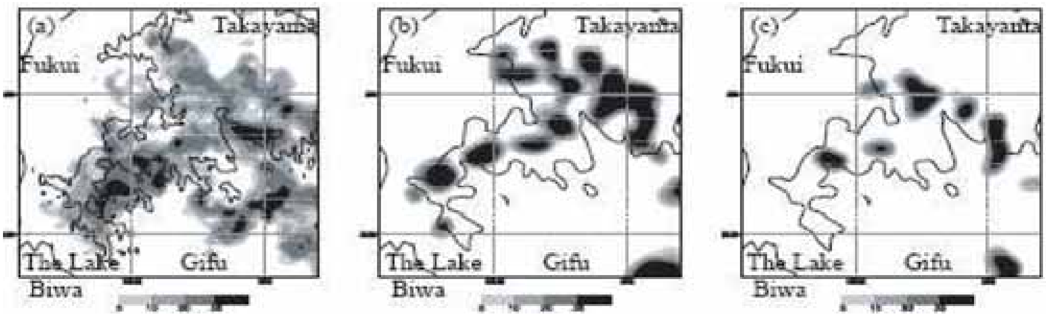

Fig. 3: Accumulated rainfall for 12JST - 18JST on 15th August 2001 with (a) Radar AMeDAS observation, (b)CASE1, (c)CASE2. The terrain heights of 0m and 500m are indicated by the thick and thin contours.

Table 1 Hydrological and environmental impacts in the Nagara River Basin.

Evaluation item	Main changes	Changes & effects
Temperature	rise	expansively or strongly influenced
Precipitation	increase ・increase deviation	expansively or strongly influenced
Evapotranspiration	Increase	expansively or strongly influenced
Snowfall &snowmelt	decrease ・period shortening	expansively or strongly influenced
Discharge ・ runoff	increase ・increase deviation	expansively or strongly influenced
Water temperature	Rise	expansively or strongly influenced
Ecosystem (fish)	suitability change /no change	expansively or strongly influenced / sparsely or hardly influenced
Phenology	timing change	expansively or strongly influenced /partly or weakly influenced
Vegetation	suitability change /no change	partly or weakly influenced
Pollen	timing change	expansively or strongly influenced /partly or weakly influenced
Agriculture	suitability change ・timing change	expansively or strongly influenced /partly or weakly influenced

Precipitation and discharge increase remarkably in summer, and increase overall as shown in Fig. 4 The air and water temperature rise, and the amount of the evapotranspiration increase all the year round.The snowfall and the snowmelt decrease, and snow melting period is shortened about one month on the average. As for fishes, suitability in summer decrease as seen in Fig. 5. While, suitability of crops and vegetation moves north from few to tens of km, Hence the necessity of change in or improvement of breed is suggested.[M. Ode, 2006]

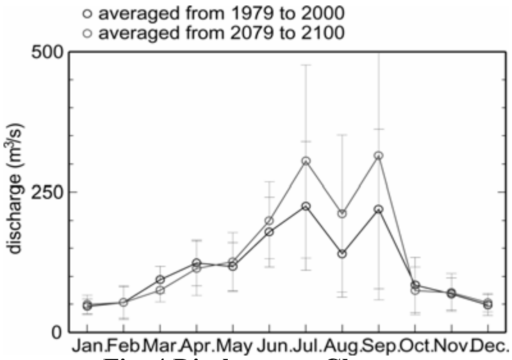

Fig. 4 Discharge at Chusetsu.

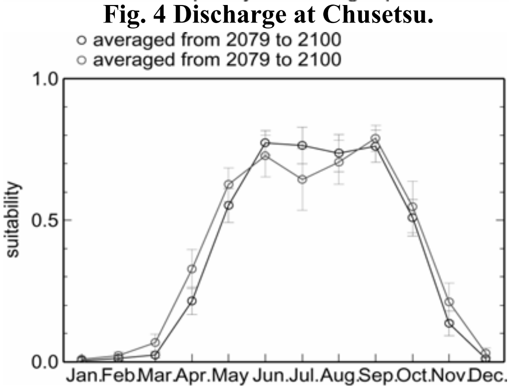

Fig. 5 Inhabitant suitability of the ecosystem (sweetfish).

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Hydro-BEAMをベースにした流域環境評価モデルの構築

池淵周一，小尻利治，萩原良巳，友杉邦雄，竹門康弘，田中賢治，浜口俊雄

要旨

本年度は Hydro-BEAM に付加するモジュール及び評価の側面についていくつか検討している。主なものは，水量・水質・生態環境を組み入れた流域水環境モデル，侵食・堆積環境と魚類の生息場，ダム下流流程と浮遊有機物動態，地表面条件とそれが積雲・降雨に及ぼす影響，地球温暖化と流域水資源環境への影響評価，である。

キーワード：Hydro-BEAM，影響評価，土地被覆，生態環境，地球温暖化