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Integrated modeling for eco-compatible management of river basin complex around Ise bay, Japan

T.Tsujimoto[a], Y. Toda[a*], T. Tashiro[a], H. Takaoka[b], K. Anbutsu[c], M. Obana[a]

[a] *Departmend of Civil Engineering, Nagoya Univeristy Furo-cho, Chikusa-ku, Nagoya, Aichi, Japan*
[b] *Aqua Restoration Research Center, Public Works Research Institute, Kawashima Kasada, Kakamigahara, Gifu, Japan*
[c] *Field Scinence Education and Research Center, Kyoto University, Oiwake-cho, Kitashirakawa, Sakyo-ku, Kyoto, Japan*

Abstract

River basin is a unit of natural runoff process and it can be considered as an assembly of flux network of water and various materials including sediment and nutrients. Inside a river basin, various landscapes are distributed, and landscape is composed of physical background, bio-chemical actions and biological aspects in associated with the local ecosystem. When the fluxes pass through a landscape, they are changed in quantity and quality and bring about various ecosystem services. Due to population increase and economic efficiency with urbanization, artificial facilities and flux networks have been added to connect multiple basins. These artificial systems have consumed fossil fuels, emitted green house gas, and degraded ecosystem. Outflow fluxes from multiple rivers degrade our facing coastal area in particular bay area. Multiple river basins connected with artificial flux networks, including a facing bay area, is here called river basin complex, where eco-compatible management methodology is required.
In the present study, we have developed an integrated numerical model for eco-compatible management of river basin complex around Ise bay in Japan, which includes following 2 sub-models: (1) Flux network model and (2) Ecosystem models of various landscapes. The model can describe the change of the material fluxes and ecosystem services under the various social scenarios on the Ise bay river basin complex.

Keyword: Eco-compatible river basin management; Ise bay; flux network; ecosystem services

* Corresponding author. Tel.: +81-52-789-5176; fax: +81-52-789-3727.
E-mail address: ytoda@cc.nagoya-u.ac.jp.

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1. Introduction

A river basin is defined as an area of watershed surrounded by water divide, and it can be considered as a fundamental unit of natural runoff processes in land area. The precipitation in the river basin is converted to ground water, surface flow and river flow in hydrological processes, which transports sediment and other fundamental materials for local ecosystem such as nutrients and organic matters in the basin. These flows of water and materials form the natural flux network in the basin. Since the ecosystem in each local landscape is connected each other through the flux network, the flux network affects the local ecosystem, and the resulting change of the local ecosystem conversely alters the flux network [1-2].

The evolutionary processes of living things are based on units which are aggregates of multiple river basins that include geology, topography, and climate as well as their changes throughout geological history. The human activities carried on in river basins have linked together multiple river basins to respond to increases of population and economic activities, which forms the artificial flux network in addition to the natural flux network. A river basin complex is defined as an aggregate of multiple and neighboring river basins, where the natural flux network and the artificial flux network are included, connected and strongly interrelated. Fig. 1 illustrates the relation between river basins and river basin complex. Since the river basin complex can be considered as a representative scale shared by the human activities and natural ecosystems, a strategy for the eco-compatible management can be found by focusing the river basin complex.

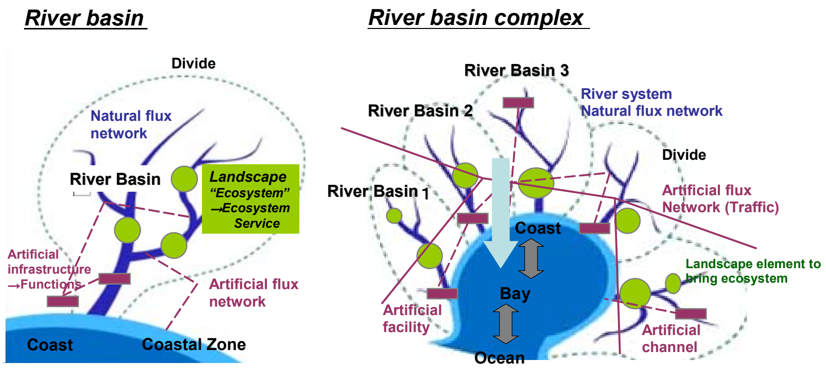

Fig. 1. (a) river basin and (b) river basin complex

2. Ise bay river basin complex

Take for example the Ise Bay river basin complex (Fig.2), which straddles the three prefectures of Mie, Gifu, and Aichi. It has an overlapping of north and south biota owing to the repeated changes in ancient Tokai Lake starting several million years ago and to ice-age changes in river systems; especially with regard to freshwater fish, there is cohesiveness in the population genetic structure engendered by the ancient Kiso River system of several ten thousand years ago.

Cities in the Tokai region have formed and continued to grow across a number of basins of rivers emptying into Ise Bay and Mikawa Bay, including the Miya River, Kushida River, Suzuka River, Kiso River, Shonai River, Yahagi River, and Toyo River. Farmland and forests have been made more efficient and monotonic, and dams have been aggressively used for developing water resources and hydropower; these changes in individual landscapes have caused the loss of habitats, and the loss of continuity of water flow has hampered the movement of organisms. What is more, developed water resources are redistributed to individual landscapes inside and outside the respective river basins via main water conveyances, including the Mie Water Project, Miyata Water Project, Aichi Water Project, Meiji Water Project, and Toyogawa Water Project. Because of this, the temporal and spatial distribution of water to each of the individual landscapes in the river basin complex has changed greatly. This is seen as the cause of, for example, river flow rate smoothing and decrease in gravel river beds, and the increase in sessile organisms. The changes in flows, sediment flux, organic matter, nutrients, and trace metals occurring because of human activities in the catchment region are seen as causes of water quality deterioration in Ise Bay and Mikawa Bay and the loss of tidal flats and seaweed beds, as well as the degradation of ecosystem in the bays.

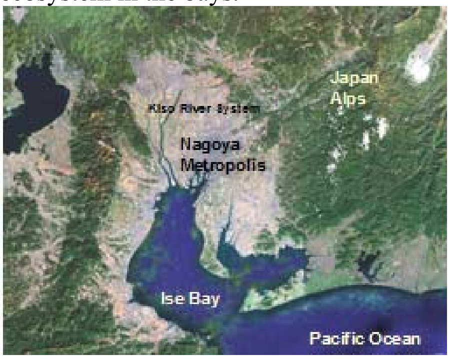

Fig. 2. Photo of Ise bay river basin complex

The Ise Bay catchment region maintains natural landscapes to an appropriate degree as human activities are carried on vigorously mainly in the cities, and the region also has topographical diversity and climate conditions peculiar to monsoon Asia. It is an appropriate place for creating and implementing a strategy for integrated management of river basin complex.

3. Research strategy

At the starting points for constructing the integrated management, clear definition of "eco-compatibility" is necessary to evaluate the eco-compatibility of target river basin complex. The concept of eco-compatibility originally comes from the wise relationship of mankind to nature that might derive a certain solution for developing sustainable society. The sound relationship to ecosystem is expected to provide mankind the various services such as food supply, resources supply, and so on, and these services are termed as "ecosystem services [3]". The ecosystem services are innately provided by renewable energy because the services are originated from solar energy through the biological actions such as primary production and food chain in ecosystem. Therefore the efficient use of ecosystem services is expected to contribute the development of sustainability by suppressing the consumption of fossil fuels, the emission of CO_2 and the loss of bio-diversity. The United Nation millennium assessment [3] summarized the various ecosystem services into "provisioning services", "regulating services", "supporting services" and "cultural services". Accordance with the circumstances mentioned above, in the present study, the degree of the eco-compatibility is measured by the degree of acceptance of the ecosystem services.

Fig.3 illustrates the schematic diagram of the models proposed in the present study. For evaluating the ecosystem services, it is necessary to develop the following 2 evaluation models: (1) flux network model and (2) ecosystem model. The flux network model, termed Tool Box 1 (abbreviated to TB1), describes the fluxes of water and materials over the river basin complex, which composed of natural runoff processes including sediment and material transports, artificial flux network in land area and flow and material transports in bay area. The ecosystem model, termed Tool Box 2 (TB2), describes the mechanism of ecosystem in each local landscape, which estimates not only the ecosystem services produced in the landscape but also the flux change due to the biological action in the ecosystem. TB1 and TB2 are interrelated through the input flux from TB1 to TB2 and the resulting flux change from TB2 to TB1. The eco-compatibility of the river basin complex is evaluated by the amount of ecosystem services estimated from TB2.

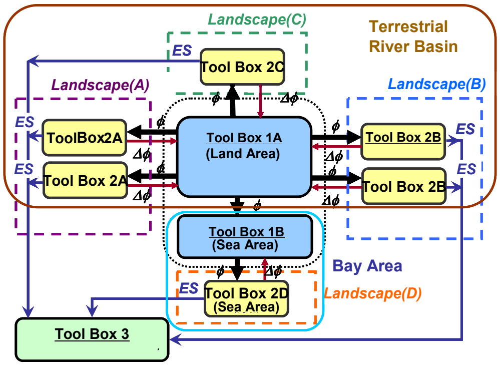

Fig. 3. Framework of the integrated modeling of river basin complex

4. Flux network model

The flux network model in land area developed here can be classified into a distributed runoff model, where the land area is divided into a number of sub-basins depicted in Fig. 4. The sub-basins are divided by confluence and divergence of rivers, and the typical scale of a sub-basin is around 2 km^2. Each sub-basin is conceptually composed of a channel and a slope, and discharge of the channel is calculated by surface runoff model and ground water runoff model from the precipitation to the slope. As for the material transports, SS (suspended sediment), TN (total nitrogen), TP (total phosphorus) and COD (chemical oxygen demand) are calculated in the channel by using transport equation for each material.

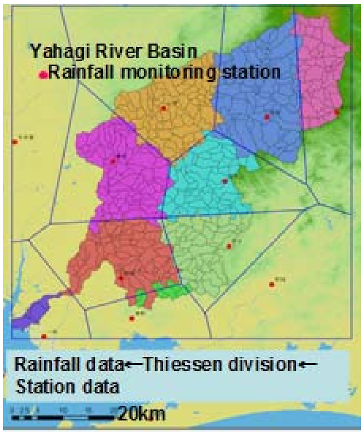

Fig. 4. Sub-basin division of the Yahagi river basin

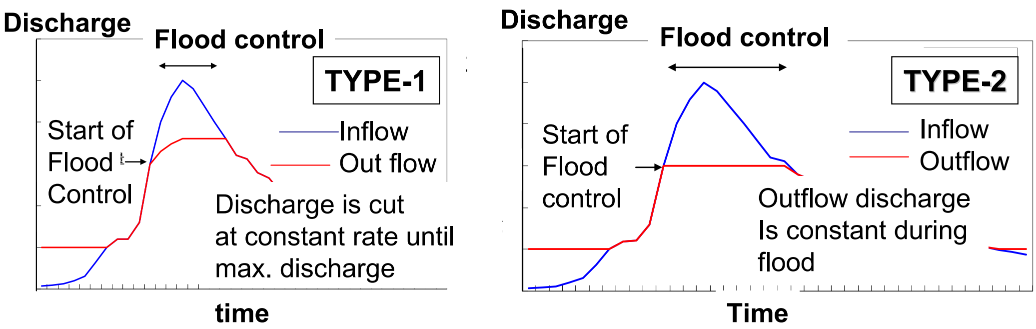

Fig. 5. Operation rules for dams

Artificial flux networks are taken into account by connecting between sub-basins in accordance with actual water use by water utilization facilities and by controlling fluxes by artificial operations. In the present analysis, dams, intakes for water resources utilization and waste water treatment systems are included as artificial facilities. As for the dam operation, two types of flood control operations depicted in Fig.5 are included in the model. About intake facilities for water resources, the water discharge of river is withdrawn based on rules for each facility. In modeling the waste water treatment facilities, the precipitation on the designed area of the facility is excluded from the runoff analysis, and the water flux equivalent to the amount of precipitation on the area is released at the relevant point of outflow in the flux networks, and the flux of the nutrient and organic matter is given by the product of released water discharge and designed concentration of each material. Non-point distributed load due to human activity is evaluated by employing unit value method with considering the treatment level of sewage system and the population. The material loads from animal waste are treated in the same manner by referring to the population of animal. The industrial loads are evaluated from the data base of industrial sales.

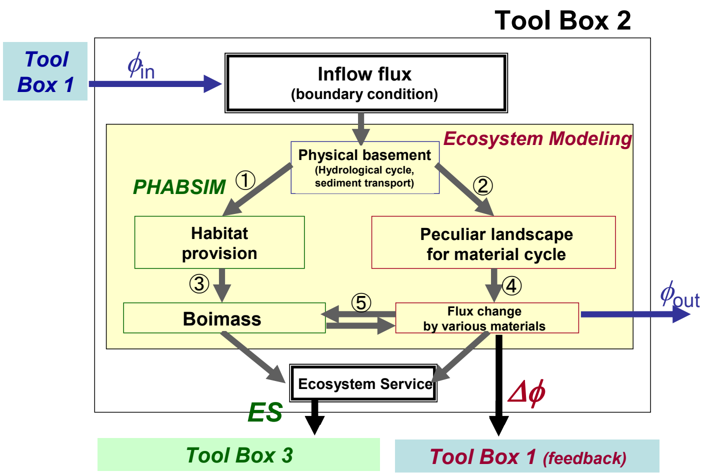

Fig. 6. Framework of the ecosystem modeling (TB2)

5. Ecosystem model

Each landscape distributed in the river basin complex consists of a physical basement and biological activities, and interaction between them provides peculiar ecosystem services of the landscape. In the present study, various types of ecosystem are modeled to estimate the ecosystem services and the resulting flux change (TB2). The framework of the ecosystem modeling developed is represented in Fig.6, where the inflow fluxes of various materials are supplied from TB1 and the flux change estimated by TB2 is inversely fed back to TB1. In the TB2, the habitat of the organisms is evaluated by physical habitat simulation and the change of the flux is evaluated by the analysis of material cycle.

The ecosystem models developed in the present study are summarized in table 1.

Table 1. Ecosystem model developed in the present study (TB2)

Item	Target landscape
Re-naturalization of man-made forest	Forest
Management of abandoned man-made forest	Forest
Construction of regulating reservoirs and utilization for paddy field	Agricultural area
Conservation and construction of conjoint of irrigation channel and over flow channel of paddy field	Agricultural area
Water management during winter for re-creating paddy field network	Agricultural area
Suppression of nutrient emission from pond mud by salinity control	Pond
Enhancement of water purification by attached algae by rehabilitation of river discharge fluctuation	River
Suppression of armoring of river bed by recreating the sediment continuities along river	River
Recreation of riffle and pool system	River
Recreation of tidal mud and shallow coastal area	Coastal area
Control of wave in coastal zone	Coastal area

6. Case studies

The numerical simulation was performed under the conditions summarized in table 2, in which the precipitation data observed at 1999 is used for all cases in order to extract the effects of differences of land use, population and policy menu on the flux network and ecosystem services. Case α corresponds to a case for implementation of various infrastructure countermeasures. Case β is a set of policy menu mainly executed by citizen's participation or non-governmental activities. Case γ is a set of policy menu for rehabilitating the ecosystem services. Case vision, which is a hybrid case of cases α, β, and γ, is prepared for compensating the weak points of case γ for reducing loads from the river basins to the bay area. Fig.7 and Fig.8 show the examples of the fluxes of various materials estimated by TB1 and the spatial distribution of ecosystem services calculated by TB2.

Table 2. Computational conditions under the various social scenarios

Case	Social condition (land use, population)	Precipitation	Comments
1960	1960	1999	
2000	2000	1999	
2030	2030 (estimated)	1999	Including the policy menus already planned
α	2030 (estimated)	1999	Infrastructure countermeasures
β	2030 (estimated)	1999	Enhancement of citizen's participation and non-governmental activities
γ	2030 (estimated)	1999	Enhancement of ecosystem service
Vision	2030 (estimated)	1999	Hybrid type of α, β and γ

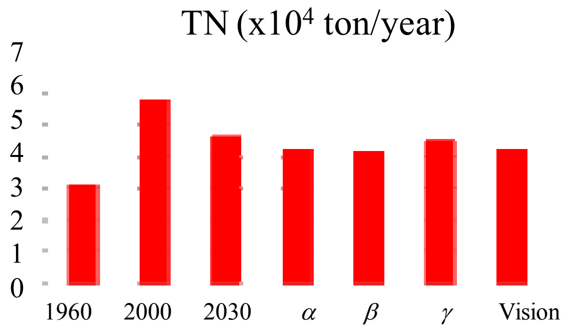

Fig. 7. Flux of total nitrogen from rivers to the Ise bay under the various social senarios

7. Conclusions

In this paper, we proposed a set of numerical models for establishing the integrated management and for evaluating the eco-compatibility of river basin complex. The evaluation model for the flux network termed TB1 was developed since the river basin complex can be considered as an aggregate of fluxes of various materials, such as water, sediment and other materials. The mechanism of local ecosystem was modeled in TB2, which estimates not only the local ecosystem services but also the flux change due to the biological actions in the ecosystem. The flux change due to the local ecosystem is fed back to the flux network, enabling us to evaluate the propagation of local ecosystem change to the subsequent area in the river basin complex. By using the numerical models, we can estimate the changes of loads from river basins to bay area and ecosystem services under various future scenarios and set of policy menus, which provides us a strategic tool for the sustainability assessment of river basin complex.

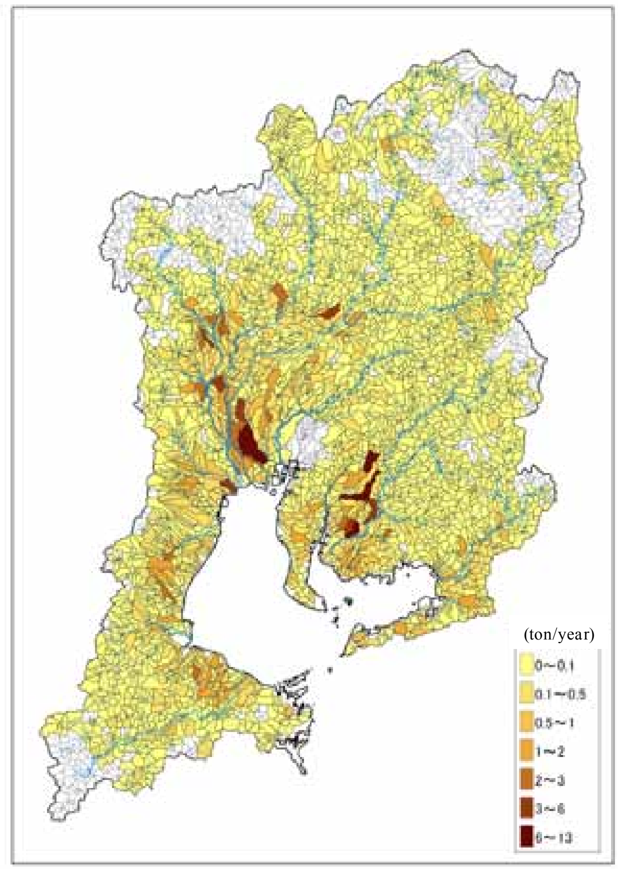

Fig. 8. Spatial distribution of denitrification estimated by TB2

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