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자연형 하천계획의 기초

Fundamentals For Nature-Oriented River Works

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INTRODUCTION – Experiences in Japan

In the last three decades the concept toward riverine environment of citizens in Japan changed a lot as well as changes of execution of river training works. Booming economy in Japan in the 1960's produced large amount of waste in all areas. It is easy to consider how large the waste water, exhaust, solid waste, and so on produced associated with modernization and advancement of the standard of living. In certain period higher consumption was admired because consumption generated new demand and production and consequently higher economic outputs. We are easily able to imagine how big the amount of waste our city life produces. Urbanization and economic development inevitably increase the amount of waste of any form. Import of crude oil is 200 million kiloliters. Garbage from household and commercial activities in Tokyo becomes 5 million tons a year. Solid waste produced from industrial activities amounts to 25 million tons a year recently only in Tokyo and also construction activities produces about the same amount of excavated soil.

Just after the high economic growth we were suffered from severe water pollution in Japan. In many rivers water quality was deteriorated very severely. But sewage works have been intensively invested since just before Tokyo Olympic games. In 1964 the ratio of sewage district was about 25% but it reached finally 100% in the area of special 23 wards in Tokyo in the fiscal year of 1994. In association with the development of sewerage works the water quality of Sumida River which flows in the central part of Tokyo was improved. For instance, in 1971 BOD was 22.3mg/l but in 1993 it reduced to 4.8mg/l. This proves that it takes long time to restore healthy environmental conditions when it was once deteriorated severely.

In 1970's due to rapid urbanization the number of people who lived in less qualified residential areas were developed mainly on economic reasons, that is, cheap land price. Instead the public sectors were forced to provide more parks and recreational zones. Easier access to rivers for recreational activities were needed and planned in urban areas. In the central part of big cities many rivers were reclaimed into parks or roads. In this movement design and facilities for human use were considered and other factors were dropped off in that stage.

In the next decade in 1970's we experienced severe damage by not very big rainfalls. This means that peak flow in densely urbanized areas increased quite a lot by the increase of runoff coefficient. The change of land use was taken into consideration in watershed planning. The point of regulation for large-scale land development, for instance, development of residential areas, is to keep the amount of runoff into rivers unchanged according to the change of surface cover. One example is the storage capacity of 900m3/ha is required in source areas of runoff.

In 1980's environmental concern took real form in watershed management. The River Council of the Ministry of Construction recommended engineers to pay attention to other factor than flood control and water resources. Rivers are able to provide multiple functions to surrounding areas and residents, such as, landscape with water, fields for recreational activities and inland fisheries, and so on. But in this stage less concern or small portion was given to whole ecosystem.

In 1990 the River Bureau of the Ministry of Construction issued the announcement on "Nature friendly river works". Naturnahen Wasserbau has been implemented in German speaking areas in Europe. But many examples were limited to small-scale rivers. On the other hand, the U.S. Fish and Wildlife Service in the middle of 1970's created the concept of Instream Flow Incremental Methodology (Stalnaker and others, 1995). Major applications were done for cold water rivers where dominant species were salmon or trout in the West Coast of the U.S. and England. After initial trials of new guidelines for nature rich river works the River Bureau announced that all river works should follow this principle of nature rich river works since 1994. Although a census on riverine environment started in 1991 in 109 important rivers which are managed under direct control of the Ministry of Construction, understanding of ecosystem is far from completion and design principles for river works how to enhance or restore natural conditions are incomplete yet.

It is summarized that the river works in Japan have experienced a couple of big changes in the paradigm which guides river related projects in recent three decades. It is obvious that nature conservation plays more and more important role in river planning and implementation of projects. A shift of emphasis occurred from securing access to water bodies, and then recreational use or landscape from the standpoint of human use only to consideration of ecosystem including all biological organisms and habitats for them.

POTENTIAL NATURE IN RIVERINE HABITATS

Conservation of nature has been discussed in the previous section. But nature is a common noun. We need scientific or technological definition of the word "nature" for baseline of technical discussion. What is nature? A concept and definition of the potential nature is proposed for common baseline of discussion (Tamai & Matsuzaki, 1996). "Potential nature" stands for the state of nature which we will encounter when surrounding conditions, such as, climate, soil, weather, land use, and so on, remains unchanged from those at present only removing the human impacts. I want to propose to use a word "nature-oriented river works" especially to design principles which are deduced from the concept of potential nature.

When we want to derive principles in nature-oriented works, we need to know essential natural features of riverine habitats. The author summarizes essential features into three, namely, 1) disturbance regime, 2) watershed is a continuum, and 3) morphological diversity. In riverine environment the most influential natural event is flood or drought. A sequence of floods and droughts controls morphology, habitat, and biological orgasms, and so on. Therefore, riverine ecosystem is under ecological succession controlled by ***disturbance regime*** given by consecutive floods and droughts. Riverine habitat is ***continuum*** in both longitudinal and transverse directions. This is a second natural feature. Sediment, pollutant loads and nutrients transported from watershed are governed by the continuity equation in three-dimensional space. Continuity in the transverse direction should be understood through relevance between a stream and a flood plain concerning not only water but also vegetation, insects, animals, and so on. A third characteristic of natural streams is morphological varieties. This is because that the boundary is composed of movable materials. Therefore, ***diversity of morphology*** is the basis to support biological diversity in riverine habitats. A step-pool system in the upper reach and a riffle-pool system in the middle reach are typical components of the natural riverine habitat. In this paper the word "nature-oriented river works" is used to explain river works which are deduced from and satisfy the principle of "potential nature in riverine environment".

CHANGE OF NATURAL DISTURBANCE REGIME VIEWED FROM ECOLOGICAL FLUSHING DISCHARGE

Since 1960's according to the increase of water demand in Tokyo Metropolis, many multipurpose reservoirs have been constructed in the upstream catchment of the Tone River basin (See Figure 1.). Today, eight reservoirs are operated. Main purposes of these reservoirs are, for example, flood control, water utilization, and generation of electricity, and we enjoy benefits already. On the other hand, it is also true that reservoir construction contains adverse effects especially on environment and ecological systems. Recently, changes in river regime which were caused by reservoir construction and consequently deteriorated fluvial ecosystem have been given higher notice.

One hint of this measure is a biological comment that algae which grow on the surface of cobbles on river bed will be deteriorated without appropriate flushing once a month after reservoir construction. This means it is desirable to have 12 small-scale or medium-scale floods in one year. Let us denote these small-scale or medium-scale floods that are effective for flushing deposited silt on the river bed as an ecological flushing discharge. If we assume that duration of this ecological flushing discharge is 5 days, daily discharge exceeds this threshold value for 60 days in one year. Analyzed results explained in Fig.2. In this paper floods which exceed Q60 (the 60th biggest discharge in one year) are called the ecological flushing discharge.

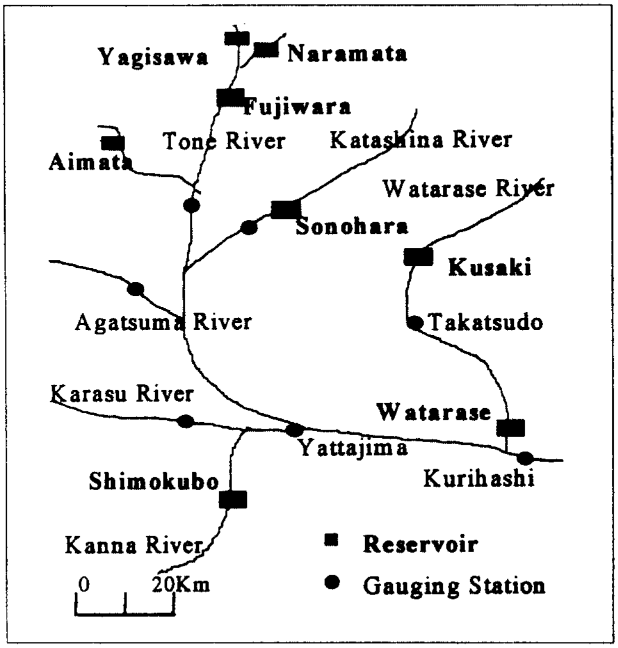

Fig.1 A schematic diagram of the upper reach of the Tone River

Figure 2 shows comparison of annual occurrence of the ecological flushing discharge at Kurihashi on the Tone River and Takatsudo on the Watarase River. Takatsudo is located just downstream the Kusaki reservoir, while Kurihashi is away from upstream reservoirs and is weakly affected by reservoirs construction. As far as Kurihashi data are concerned, remarkable change can not be observed before and after the construction, on the other hand, annual occurrence of the ecological

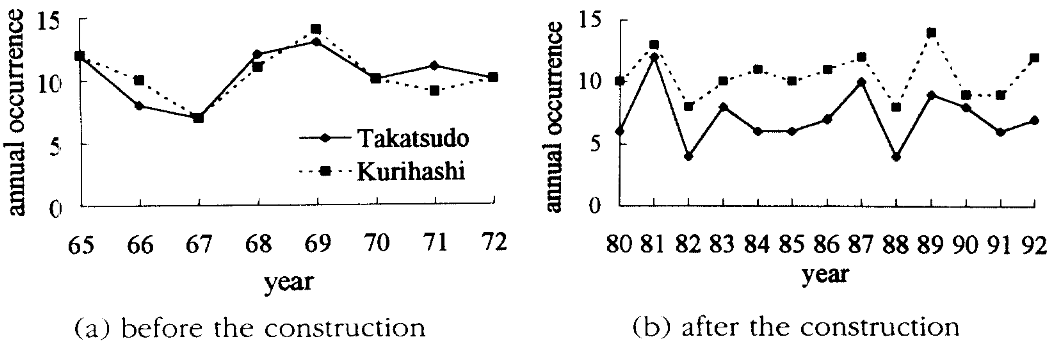

Fig.2 Comparison of annual occurrence of ecological flushing discharge

flushing discharge at Takatsudo had reduced by 3 or 4 times on average. One of the cause of this reduction is assumed that artificial reservoir operations smoothed out flood discharges and consequently made the duration of each ecological flushing discharge longer (Refer to Fig.3(a)). We defined the ecological flushing discharge and paid attention to numbers of occurrence in a year.

Table 1 Average and standard deviation of the interval of ecological flushing discharge

July to September	before	after
average(day)	16.6	15.6
standard deviation(day)	3.6	3.6
October to June	before	after
average(day)	41.5	63.8
standard deviation(day)	6.6	8.8

The interval of two consecutive flushing discharges is considered in a next step. Table 1 shows average and standard deviation of the interval of two consecutive flushing discharges for both summer (July to September), when algae need more ecological flushing discharge than the other seasons, and other seasons (October to June) at Takatsudo. Table 1 clearly shows that little change is observed for summer events (flood season), but in a dry season (from October to June) conspicuous prolongation of the interval are observed. This may be attributed to exploitation of water resources. In the period between March and June we have relatively large amount of precipitation in Kanto region. But demand of irrigation water is large. Therefore, spill from reservoirs is small. In the period between October and February we experience natural drought period. Furthermore, demand of municipal water is constant throughout the year. Therefore, in natural drought period we have difficulty to release water from a reservoir.

AUGMENTATION OF CONSERVATION FLOW

If we assume that former river regime (before the reservoir construction) is better than present one (after the reservoir construction) environmentally, better features should be restored by reservoir operations. If it is possible to augment discharge from a reservoir, ecological flushing discharges will be restored as in the pre-construction condition. In actual reservoir operation, however, each reservoir may have no enough capacity for ecological use. Then a network operation of reservoirs linking several reservoirs by pipes will be useful because we are able to use regional variability in discharge advantageously. Figure 3 shows natural flow and simulated flow, which will be realized by linking between reservoirs, for daily discharge at Takatsudo gauging station.

In a mathematical simulation, Kusaki reservoir, Sonohara reservoir and Shimokubo reservoir were connected by pipes for water transfer, and, System Dynamics was used for actual calculation. Figure 3(b) shows the result of simulation of available release from the reservoir by this water transfer. It is shown that occurrences of small-scale or medium-scale floods are increased by augmentation for ecological flushing and river regime is improved environmentally (Tamai, Emura, & Matsuzaki, 1997).

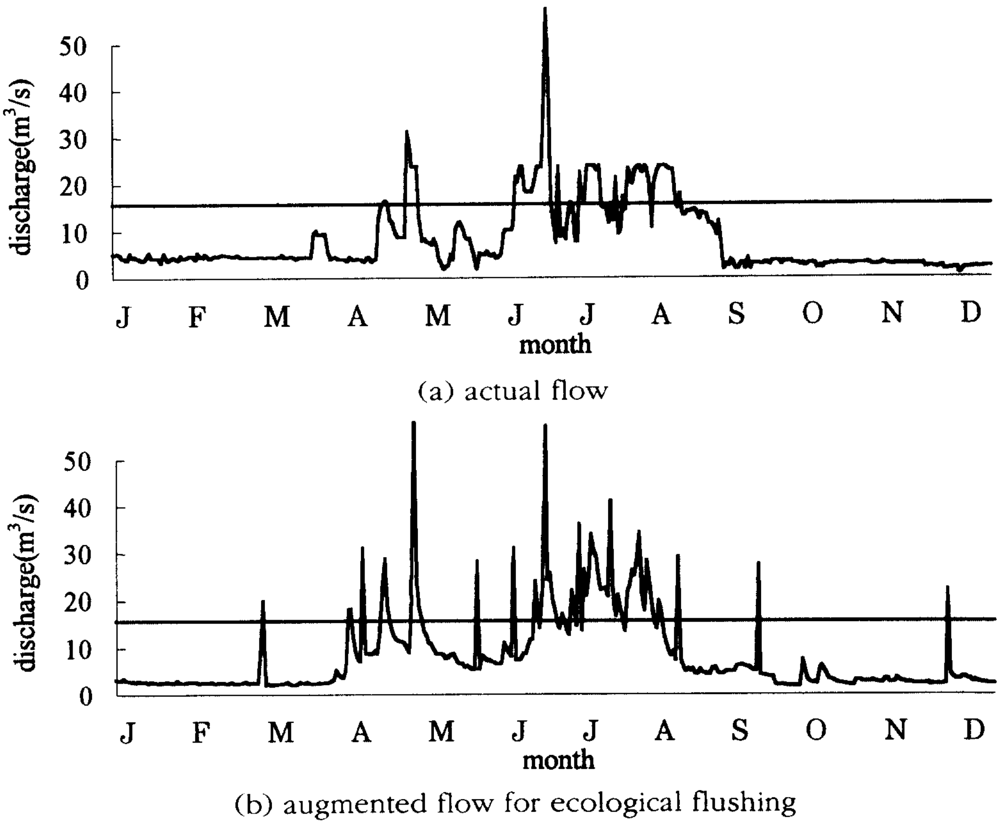

Fig.3 Actual flow and augmented flow at Takatsudo for daily discharge of the year of 1984

AN EVALUATION OF FISH HABITAT USING FUZZY THEORY

Review on Aquatic Habitat Evaluation Techniques

Japan is composed of islands. Then a few primary fresh water fish inhabit, almost fresh water fish are classified as secondary or migratory fish and species are variety. Streams provide fisheries for mid- to high- priced food species such as Ayu (Plecogloussus altivelis altivelis), as well as recreational fishing. The fishing rights are owned only by cooperatives, which are organized by commercial fishermen and processors to jointly carry out economic activities, and which are obligated to produce and stock fish and also manage habitat in return for their fishing rights. Recreational anglers, whose numbers have been rapidly increasing, have to buy a temporary license from local cooperatives. In recent years ecological aspects in streams have been a center of public attention. Nature friendly river works by the Ministry of Construction have been implemented since 1990 in Japan. However, concrete concepts and technical principles for suitability of aquatic habitat to determine ecological instream flow that provides fundamental idea for genuine nature-oriented river works have not been formulated yet.

The Instream Flow Incremental Methodology (IFIM) has been widely used to estimate the relationship between discharge and fish habitat in rivers (Bovee, 1982). The Physical Habitat Simulation Model (PHABSIM) is the core of the IFIM. The methodology consists of the calculation of a weighted useable area (WUA) which is represented by available fish habitat. Various biological assumptions and the apparent imprecision of PHABSIM have been criticized (e.g., Gore and Nestler, 1988; Elliott, 1994; Shirvell, 1994). Those criticisms include 1) not applicable for dynamic flow, 2) dependence on hydraulic variables, 3) neglect of biological diversity, and 4) inappropriate for complex cold water system and warm water system.

Methodology for Evaluation of Fish Habitat

So far as biocenosis is concerned, the weights of the environmental factors are not a universal value, but contain swinging because the habitat field is expanded and changed by both a struggle for existence and by external disturbances. A certain fish's preference to environmental factors is a vague value which changes by the situation. It can therefore be described as a fuzzy number. In other words, the relationship between the set of the habitat potential of fish species and the set of environmental factors is fuzzy. In order to evaluate the habitat environment of a certain fish species comprehensively, the reference value of all the combinations of each environmental factor should be decided. This measure cannot be identified because it depends on the complex behavior of biocenosis. However, the weights of the environmental factors can be considered to be a rate that contributes to the integrated evaluation value. Namely, the weights can be defined as fuzzy measures. A fuzzy measure explains the effect of the combination of the interaction between partial sets, that is, combinations of each environmental factor. When the value of a fuzzy measure of an environmental factor is applied to the fuzzy measure, μ, the integral value can be regarded as the evaluation score.

The avoidance curve of Medaka (***Oryzias latipes***) for toxic contaminants was illustrated (Hidaka and Tatsukawa, 1985). The water quality and the water temperature are important environmental factors that directly affect fish that inhabits in the area. Therefore, it is necessary to handle these independently of preference. In order to express such avoidance, the fuzzy measures are defined by the following equation.

$$(1) \quad \begin{cases} \mu(\{\text{ water temperature }\}) = -1.0 \\ \mu(\{\text{ water quality }\}_n) = -1.0 \end{cases}$$

where, n= number of contaminants (e.g., NH_2CL, LAS, fenitrothion)

Application

It can be said that the set of the representative three fish species and sets of six environmental factors relative to fish inhabiting an area are in a fuzzy relation as shown in Eq. (2). In the case of the species C, the fuzzy measure is expressed as Eq. (3). It is understood that according to the rules of fuzzy sets, the sum does not have to equal 1.0 even if each fuzzy measure of an environmental factor is added.

(2) R =

	velocity	depth	substrate	cover rate	vegetation	distance between riffles and pools
species A	1	−0.82	0	0	0	0
species B	−0.94	1	0	0.80	0.89	0
species C	0	0	1	0.71	0	−0.83
species D	1	−0.67	−0.77	0	0	0

$$
(3)\begin{cases}
\mu(\{\text{substrate value, cover rate, distance between riffles and pools}\}) = 1.0 \\
\mu(\{\text{substrate value}\}) = 0.5 \\
\mu(\{\text{cover rate}\}) = 0.3 \\
\mu(\{\text{distance between riffles and pools}\}) = 0.4 \\
\mu(\{\text{substrate value, cover rate}\}) = 0.7 \\
\mu(\{\text{substrate value, distance between riffles and pools}\}) = 0.8 \\
\mu(\{\text{cover rate, distance between riffles and pools}\}) = 0.6
\end{cases}
$$

By the integration of the evaluation score of an individual environmental factor according to the definition, the integral value becomes the comprehensive evaluation score of the habitat environment. The evaluation score of an individual environmental factor is assumed to have satisfied the observed distribution of an environmental factor and the adaptation with preference curve.

That is, overlapping determines if a score is in the entire river or a specific section. Classification can be based on fish experts' opinions or the photographs, etc. when there is no preference curve or authorized score.

Take as an example the case where the habitat environment of the species C is evaluated. The suitability curve only of the sediment is assumed as shown in Fig.4, and individual score of the cover rate and the distance between riffles and pools are assumed to be judged from the fish's mode as shown Table 2. It is assumed that the score is 5 points out of 10 when the preference curve of the sediment and the adaptation of the sediment investigation in the observation section are 50%. And the individual score of cover rate and the distance between riffles and pools are seven points and three points respectively.

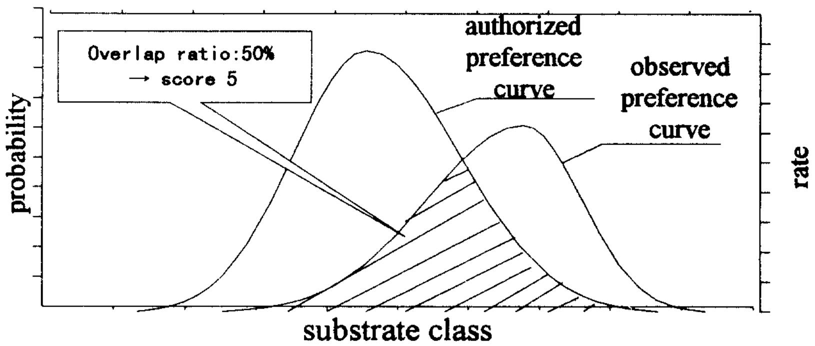

Fig. 4 Determination of substrate score by overlap area

Individual scores of the three factors are shown in Eq. (4). Choquet integration is done according to the definition. Namely, the integrated evaluation value, that is to say, the comprehensive evaluation of dark club in the observed section is

(4)
$$\begin{cases} f(\text{substratevalue}) = 5 \\ f(\text{coverrate}) = 7 \\ f(\text{distancebetweenriffles and pools}) = 3 \end{cases}$$

(5)
$$(c) \int f d\mu = 1.0(3-0)+0.7(5-3)+0.3(7-5) = 5.0$$

5.0 as shown in Eq.(5) out of 10. As a result, when the water temperature and the water quality are suitable, the fish do not take refuge. However, the score becomes negative like Equation (6) when the water temperature or the water quality is in the range as shown

Table 2 Determination of cover rate and distance between riffles and pools by classified scores

cover rate (%)	distance between riffles and pools (m)	score
0.0 ~ 1.0	400 ~	0
1.0 ~ 2.0	300 ~ 400	1
2.0 ~ 3.0	250 ~ 300	2
3.0 ~ 4.0	200 ~ 250	3
4.0 ~ 5.0	160 ~ 200	4
5.0 ~ 6.0	120 ~ 160	5
6.0 ~ 7.0	80 ~ 120	6
7.0 ~ 8.0	50 ~ 80	7
8.0 ~ 9.0	20 ~ 50	8
9.0 ~ 10.0	10 ~ 20	9
10.0 ~	0 ~ 10	10

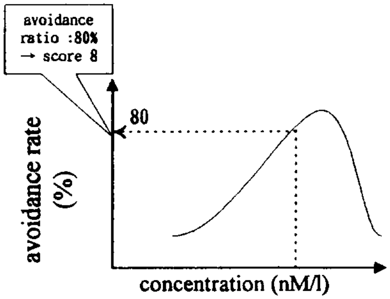

Fig. 5 The avoidance curve for a toxicant

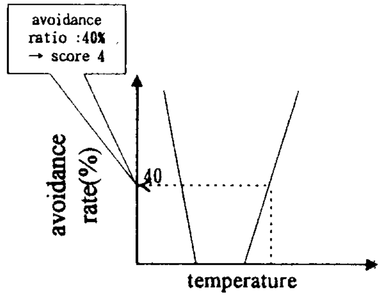

Fig. 6 The avoidance curve for the water temperature

in Figures 5 and 6. If the score becomes negative, it is necessary to take a strategy other than the proposed river work.

(6) $(c)\int fd\mu+(c)\int gd\mu = 5.0+\{-1.0(4-0)-1.0(8-4)\} = -3.0$

This evaluation method is an objective index of the river environment. For instance, which river or which section is suitable habitat for fish when river improvement is planned, aiming at adjusting an evaluation score of all the representative fish species to 6.0 or more, are compared in the whole river or a specific section.

It is pointed out that application of fuzzy theory for evaluation of fish habitat has merits given as below: 1) Fish activities include vagueness based on the competition and avoidance. 2) A comprehensive method of evaluating habitat environment that considers the vagueness of the fish, based on the fuzzy theory, is proposed. This evaluation method reflects not only fish preferences but also avoidance. and 3) The proposed method overcomes the criticisms of the PHABSIM.

ANALYSIS ON COST AND BENEFIT OF ENVIRONMENTAL FLOW

In this paper environmental flow is defined as stream flow for enhancement of better environmental conditions to keep rivers healthy including healthy habitat for ecosystem. It is shown in Fig.3 that increase of release from reservoirs by comprehensive operation of several reservoirs is able to improve flow regime for ecological flushing. But neither cost and benefit nor methodology are complete for economic analysis of environmental flow. In order to establish a decision support system for nature-oriented river works it is necessary to clarify the basis of economic analysis.

Cost evaluation

Water right for hydropower generation should be renewed every thirty years. Since 1988 the condition of approval for renewal of water right for hydropower is to release a specified amount of water to downstream as conservation flow. The guideline for conservation flow is from $0.1m^3/s$ to $0.3m^3/s$ per $100km^2$ of catchment. To evaluate the cost of environmental flow the loss of output by the release of conservation flow is calculated. The author considered that theelectric power companies accept the loss as necessary expenditure to carry social responsibility of enterprises to exist as environment conscious organizations.

In the Tone River basin the loss of energy production then loss of income was evaluated assuming the release of conservation flow is $0.3m^3/s$ per $100km^2$ catchment area. The results are summarized in Table 3. Catchment area, type of turbines, and effective head of each power station were collected (Dam Association, 1995) for calculation of the reduction of generation of electricity in one year. In the Tone river basin total loss of income of electric power company amounts to 10.5 billion Japanese yen (about US$86 million). This is considered the price or cost of environmental flow to sustain minimum aquatic life. This estimation was done in a first step to know the order of cost of environmental flow and may be too simple to apply to real situations. We need to study more details of each habitat before to reach to a firm conclusion.

Table 3 Loss of income for release of conservation flow

Name of rivers	Number of power station	Annual loss in billion yen
Oku Tone Area	11	3.34
Akaya River	5	0.39
Katashina River	14	1.82
Agatsuma River	18	2.47
Karasu/Kanna River	3	0.26
Watarase River	6	0.65
Kinu river	22	1.59
Total	79	0.52

Benefit of environmental flow

Contingent value method was used to evaluate the benefit of environmental flow. The survey was performed at the Naramata Dam in the Tone River basin. But the number of samples was rather small, the author want to just mention a tentative value. The benefit tentatively calculated is around 11,000 Japanese yen, each year for one family, which is reasonable when we compare a couple of previous attempts.

Then an input-output analysis was carried out to evaluate the impact of environmental flow on regional economy in Kanto area. The interindustry relations table of the year of 1990 was used for 46 sectors (Ministry of Int. Trade & Industry, 1995). Annual loss of 10.5 billion yen is considered to be the tax charged to electric power companies to conserve better environment.

Because value added of electric power industry in 1990 is 224.8 billion yen, the tax corresponds to the increase of value added in the magnitude of 0.47%. The influence of this rise is calculated. Table 4 shows influence on sectors summarized into ten. Electric power

Table 4 Influence of environmental flow on the economy of Kanto region

ector	Economic effect (Million yen)
Agriculture & Fishery	116
Mining	56
Food & Tobaco	769
Metal	2,549
Machinery	4,029
Other products	4,153
Construction	1,714
Public Utility	20,329
Commerce & Transport	2,704
Service & Others	5,830
Total	42,249

Table 5 Ten setors of most largely influenced

		Economic effect (Million yen)
1	Steel Product	1,603
2	Chemical Product	1,567
3	Commerce	1,520
4	Service to Individuals	1,467
5	Transport	1,184
6	Housing	1,141
7	Automobile	1,108
8	Electronics	1,086
9	Service to Companies	1,011
10	Education & Research	935

companies are classified into the public and utility sector. Therefore, this sector shows the biggest influence.

Most heavily influenced 10 sectors among 45 other than electric power industry are shown in Table 5. The total amount of influence is estimated to be 42.2 billion yen. This amount is less than that calculated by CVM introduced in the beginning of this section. This value added is just 0.011% of the total products in Kanto region of 1990. Therefore, if a new tax is introduced for augmentation of conservation flow, the influence will be limited within narrow range in the whole industrial activity (Shirakawa, Matsuzaki & Tamai, 1997).

CONCLUDING REMARKS

Trend in Japan concerning the concept on riparian environment for four decades is reviewed. Potential nature in riverine habitat is defined and the most influential components are summarized to be 1) natural disturbance regime, 2) continuum of a river basin, and 3) diversity of morphology. Nature-oriented river works are defined with relation to potential nature. Fundamental components that are necessary to build up a decision support system for nature-oriented river works are formulated and solutions on a couple of components are explained in this paper.

Disturbance regime is analyzed under the influence of reservoir construction. It is clarified that human control of a reservoir gives modification to river regime, which is unfavorable to especially ecosystem near river bed. A way how to augment environmental flow is sought by a comprehensive operation of multiple reservoirs forming a network. This type of countermeasure is shown effective through an example in the Tone River system.

Habitat analysis considering fuzzy nature of biocenosis and natural disturbances is developed. It is shown that the method described in this paper is able to give a more quantitative evaluation of riverine habitat. In the last part of this paper cost and benefit of environmental flow are shown. Although the analysis shown in this paper is still primitive, the author wants to emphasize that economic analysis is essential to a decision support system for planners of infrastructures including conservation of nature.

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