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Review

History and Current Situation of River Management using Physical Habitat Models in the U.S. and Japan

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History of Instream Flow Incremental Methodology (IFIM)
Following the large reservoir and water development era of the mid-twentieth century in North America, resource agencies became concerned over the loss of many miles of riverine fish and wildlife resources in the arid western United States. Consequently, several western states began issuing rules for protecting existing stream resources from future depletions caused by accelerated water development. Many assessment methods appeared during the 1960's and early 1970's. These techniques were based on hydrologic analysis of the water supply and hydraulic considerations of critical stream channel segments, coupled with empirical observations of habitat quality and an understanding of riverine fish ecology.
Following enactment of the National Environmental Policy Act (NEPA) of 1970, attention was shifted from minimum flows to the evaluation of alternative designs and operations of federally funded water projects. Methods capable of quantifying the effect of incremental changes in stream flow to evaluate a series of possible alternative development schemes were needed. This need led to the development of habitat versus discharge functions developed from life stage-specific relations for selected species, that is, fish passage, spawning, and rearing habitat versus flow for trout or salmon.
During the late 1970's and early 1980's, an era of small hydropower development began. Hundreds of proposed hydropower sites in the Pacific Northwest and New England regions of the United States came under intensive examination by state and federal fishery management interests. During this transition period from evaluating large federal reservoirs to evaluating license applications for small hydropower, the Instream Flow Incremental Methodology (IFIM) was developed under the guidance of the U.S. Fish and Wildlife Service (USFWS).

Key words : river management, physical habitat model, IFIM, PHABSIM

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FRAMEWORK OF IFIM[1]

Fig. 1 shows the components and model linkages of IFIM, and Fig. 2 shows activities and information flow involved in an IFIM study. This methodology attempted to integrate the planning concepts of water supply, analytical models from hydraulic and water quality engineering, and empirically derived habitat versus flow functions. This methodology produced simulations of the quantity and quality of 'potential habitat' resulting from proposed water development, illustrated through a series of alternative flow regimes. In the original IFIM, four interrelated activities or phases are required to complete the process.

Phase 1: Problem identification and diagnosis

This phase consists of two principal components: (1) a legal and institutional analysis to define the problem setting and the probable context of its resolution, and (2) an issues analysis that identifies concerns of the various stakeholders of a problem and the information that will be needed to resolve the problem.

There is a big difference in the US between a decision to license a hydropower project under the rules of the Federal Energy Regulatory Commission (FERC) and a decision to establish a minimum flow level in a state park. Because it is important to use the appropriate methodology in each of these different cases, the developers of the IFIM recommended that an "institutional analysis" be conducted at the beginning of each instream flow study. Software called Legal-Institutional Analysis Model (LIAM) has developed to support this process.

Phase 2: Study planning

This phase involves a comparison of information needs with information already available. The difference between needed and available information is the basis for the study plan. During the formulation of a study plan, an interdisciplinary team must agree on study objectives and deadlines, appropriate models and data requirements, levels of temporal and spatial detail, roles and responsibilities, products and milestones, and project budgets. Study planning should also develop a common understanding of the analytical approach that will be used for evaluating alternatives.

Phase 3: Study implementation

This phase involves data collection, model calibration, and verification of model input and output. Quality assurance is necessary every step in study implementation to ensure that the information produced by IFIM's component models, such as Stream Network Temperature model (SNTEMP) and Physical Habitat Simulation Model (PHABSIM), is as accurate and realistic as possible. Macro habitat analysis using SNTEMP and/or other water quality models limits the range of a river where target species can inhabit, and micro habitat analysis using PHABSIM and/or other habitat models evaluate the segregation of target species in the inhabitable range of the river. Without trust worthy data it is difficult to accurately compare alternatives that might be proposed during the next phase.

Phase 4: Alternatives analysis/problem resolution

During this phase, an agreed-on set of baseline hydrologic conditions provides the essential point of reference. All parties to the decision process may then have their preferred alternatives compared with the baseline conditions. The group can collectively examine all alternatives for their effectiveness, physical feasibility, risk of failure, and economic considerations. Problem resolution is accomplished through negotiation and compromise, based on the evaluation of competing alternatives. Interdisciplinary teams composed of various stakeholder groups can derive solutions through iterative problem-solving to achieve some balance among multiple and often conflicting uses of water.

SUCCESS AND MISUSE OF IFIM AND PHABSIM IN THE U.S.

NEPA guidelines for examining alternatives and hydropower relicensing forced United States decision makers to balance potential conflicts among users of the riverine resources. Incremental methods became the tools of choice for quantitatively describing the consequences of alternative ways

[1]This section mainly consists of copied paragraphs and figures from Bovee *et al.* (1998) with some modifications.

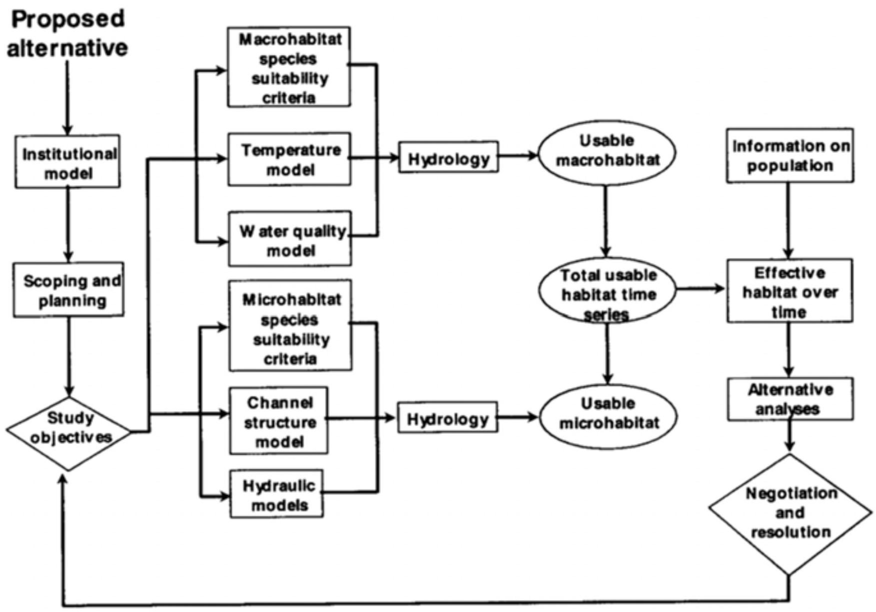


Fig. 1. Schematic diagram of the components and model linkages of IFIM (Bovee *et al.* 1998).

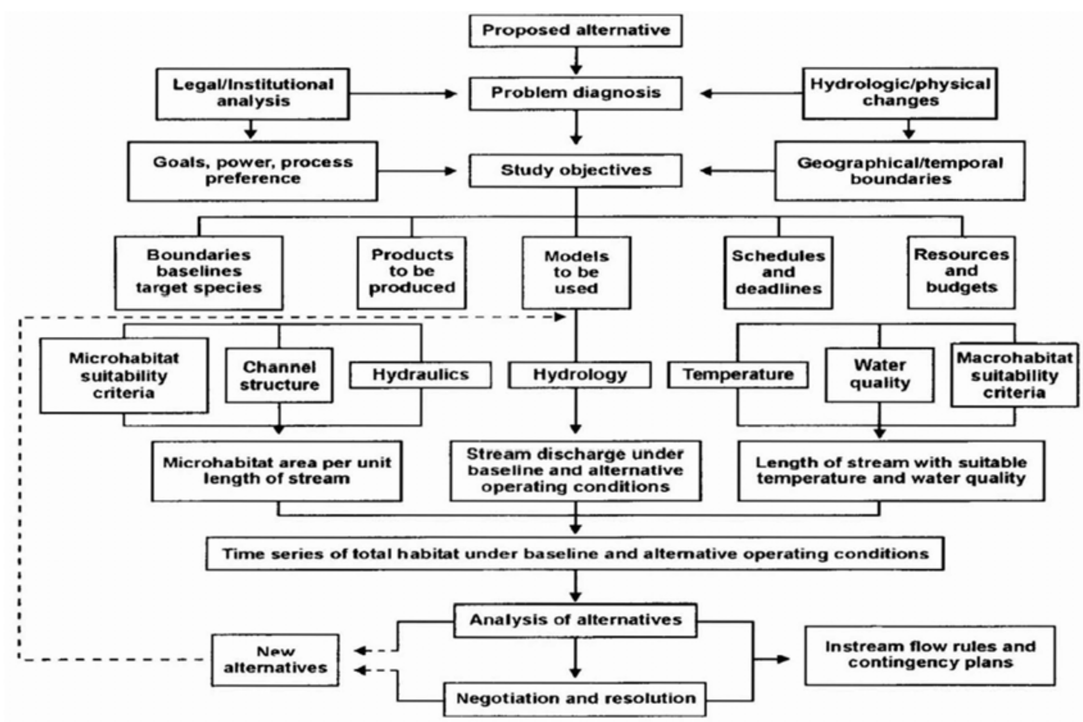
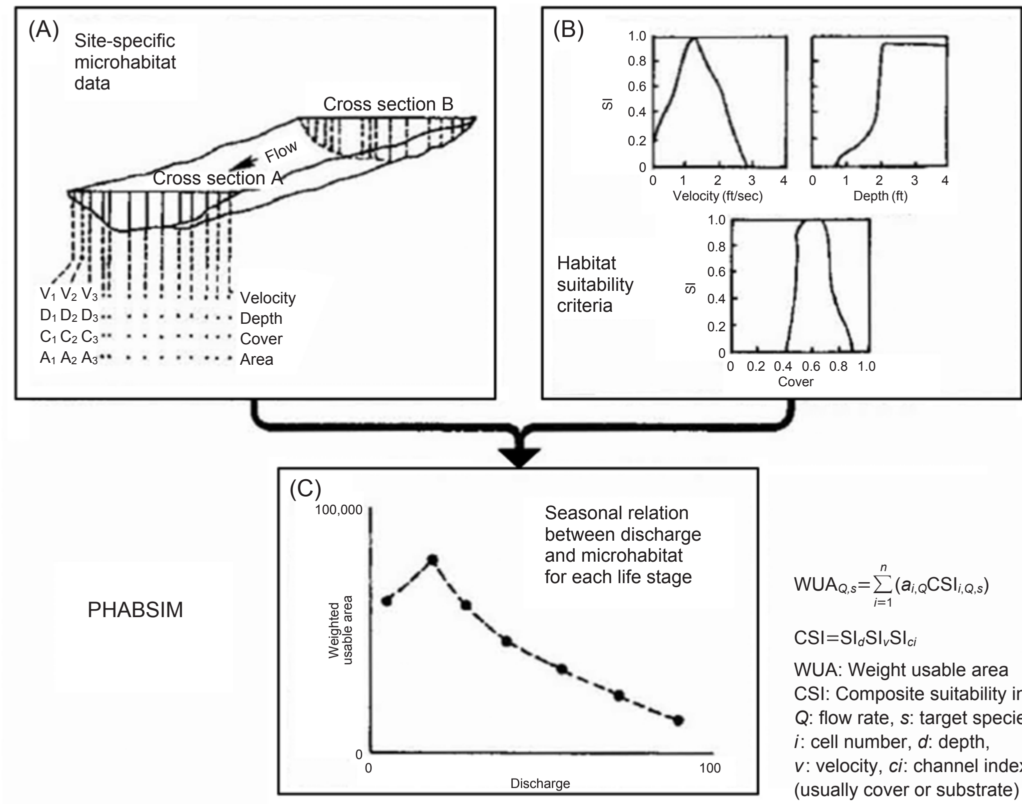


Fig. 2. Schematic diagram of activities and information flow involved in an IFIM study (Bovee *et al.* 1998).

of managing flowing waters, setting the stage for negotiation among various interest groups and better informing the decision makers in their role in conflict solution. The Federal Regulatory Commission (FERC) web site (http://www.ferc.gov/industries/hydropower/gen-info/guidelines/eaguide.pdf) has various references that show they are encouraging use of IFIM in hydropower license applications. Also, IFIM is required or recommended by several state governments as the preferred methodology



$$WUA_{Q,s}=\sum_{i=1}^{n}(a_{i,Q}CSI_{i,Q,s})$$

$$CSI=SI_d SI_v SI_{ci}$$

Fig. 3. Conceptualization of how PHABSIM calculates habitat values as a function of discharge. (A) First, depth (Di), velocity (Vi), cover conditions (Ci), and area (Ai) are measured or simulated for a given discharge. (B) Habitat Suitability Index (HSI) model (it is also called as Habitat Suitability Criteria; HSC) is used to weigh the area of each cell for the discharge. Composite suitability index is calculated as a product or geometric mean of SIs for depth, velocity, and cover. The habitat values for all cells in the study reach are summed to obtain a single habitat value for the discharge. The procedure is repeated for a range of discharges to obtain the graph (C) (Stalnaker *et al.* 1995).

for assessing instream flow problems. There is a fairly large body of applications of this approach to habitat assessment in the U.S.

However, there are very few applications which followed the holistic IFIM approach described in the previous section. Most users have been rather simplistic applications of the PHABSIM model alone. Recently consulting community in the US has become familiar with running the PHABSIM and collecting the data, and the number of the requests for technical assistance to USGS has decreased. The increase in such requests to USGS has come from other parts of the world, especially from Spanish speaking countries and Iran. Many people misunderstand that IFIM is equal to PHABSIM. But in reality, PHABSIM is merely a part of IFIM, or even not necessarily be used in IFIM.

The basic idea of PHABSIM is rather simple (Fig. 3). It assumes that fish abundance in a river has relation with the value of habitat in the river, and the value of habitat is described by multiplying habitat quantity and habitat quality. Habitat quantity is usually described as surface area of a section, and habitat quality is described as suitability or preference of the target species to the section. Suitability or preference is described as a function of velocity, depth, and substrate or cover. These physical parameters are thought to have relation with reproduction, food, and predator/competitor in ecological point of view. This simplicity of the concept, and the existence of the downloadable PHABSIM software, might be one reason of its wide acceptance.

However, the output of PHABSIM is not enough for management purpose. In IFIM, you need to have a habitat time series as a starting point of comparing alternatives (Fig. 4). By using a habitat time series, you may conduct various analyses taking life stages of target species into account. Some examples are given in Fig. 5.

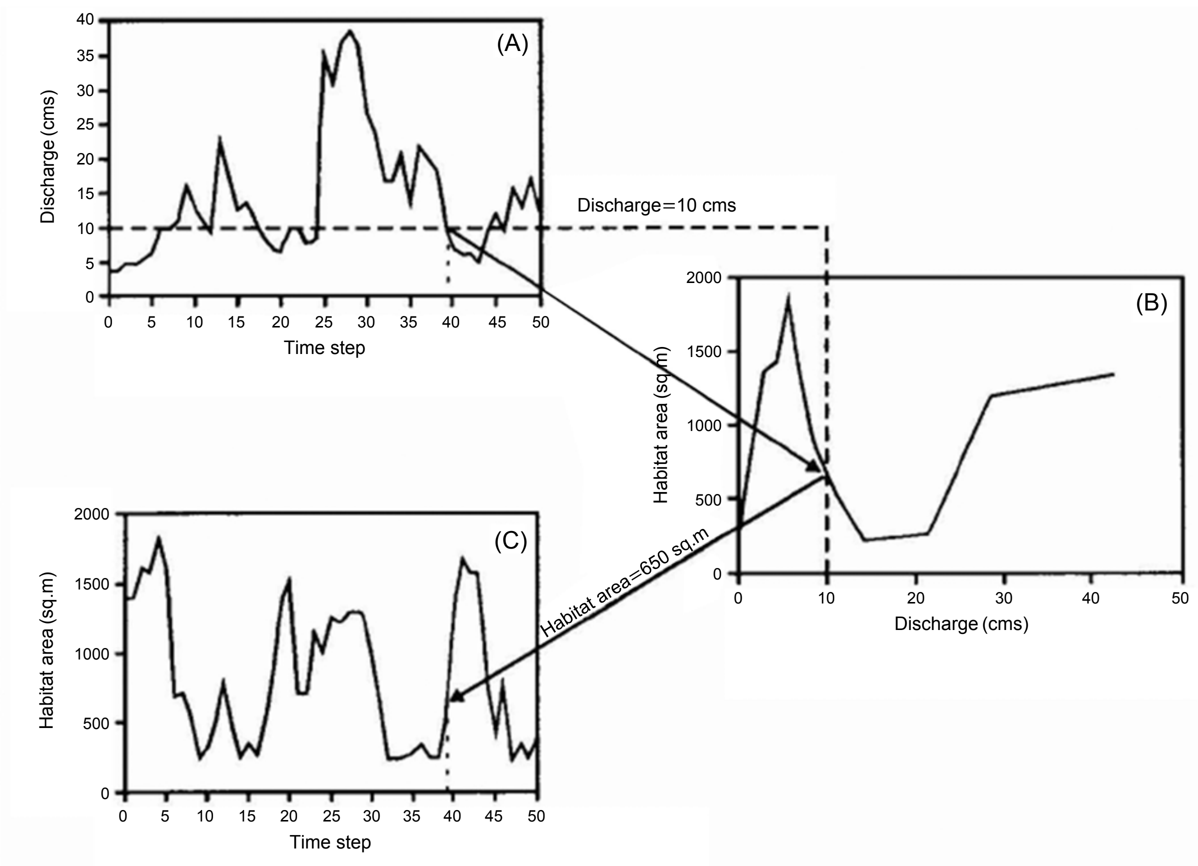


Fig. 4. Ingredients for constructing a habitat time series: (A) the discharge associated with a time-step is read from the hydrologic time series, (B) the total habitat area for the selected discharge is obtained from the discharge-habitat relationship, and (C) the total habitat area for the time step is entered into the habitat time series (Bovee *et al.*, 1998).

Dr. Stalnaker (2011) warns that "Specifically note that PHABSIM output is NOT the product but rather it is the INPUT to habitat modeling using habitat time series (when combined with temperature/water quality modeling giving TOTAL usable habitat over the stream lengths of interest as a function of flow) and the life history of the aquatic species of interest. This analysis allows the practitioner to identify potential habitat bottlenecks that may be induced by water management". He also add a warning by quoting a sentence from Annear 2004, "Instream flow prescriptions resulting from an IFIM analysis always incorporate seasonal (intraannual) and water year type (interannual) flow recommendations. Practitioners who prescribe single, minimum flow values by examining the flow/habitat or flow/temperature relation (e.g., output from PHABSIM or SNTEMP) and present the results as an IFIM analysis are misusing the methodology and fueling the controversy...".

More recent development in the US has focused on linkage to water resource operations and water routing, salmonid fish population response to flow and habitat manipulations, and large river sampling emphasizing two-dimensional hydraulics.

HISTORY AND CURRENT SITUATION IN JAPAN

In Japan, citizens started to notice about the importance of river environment, and imported the idea of "Natunaher Wasserbau (Near nature water works)" from Europe in the late 1980's. The idea was eventually authorized by government in 1990, but still there was no clear image how to accomplish it. The idea from Europe emphasized the creative thinking and careful observation of nature, and it gave embarrassment and confusion to civil

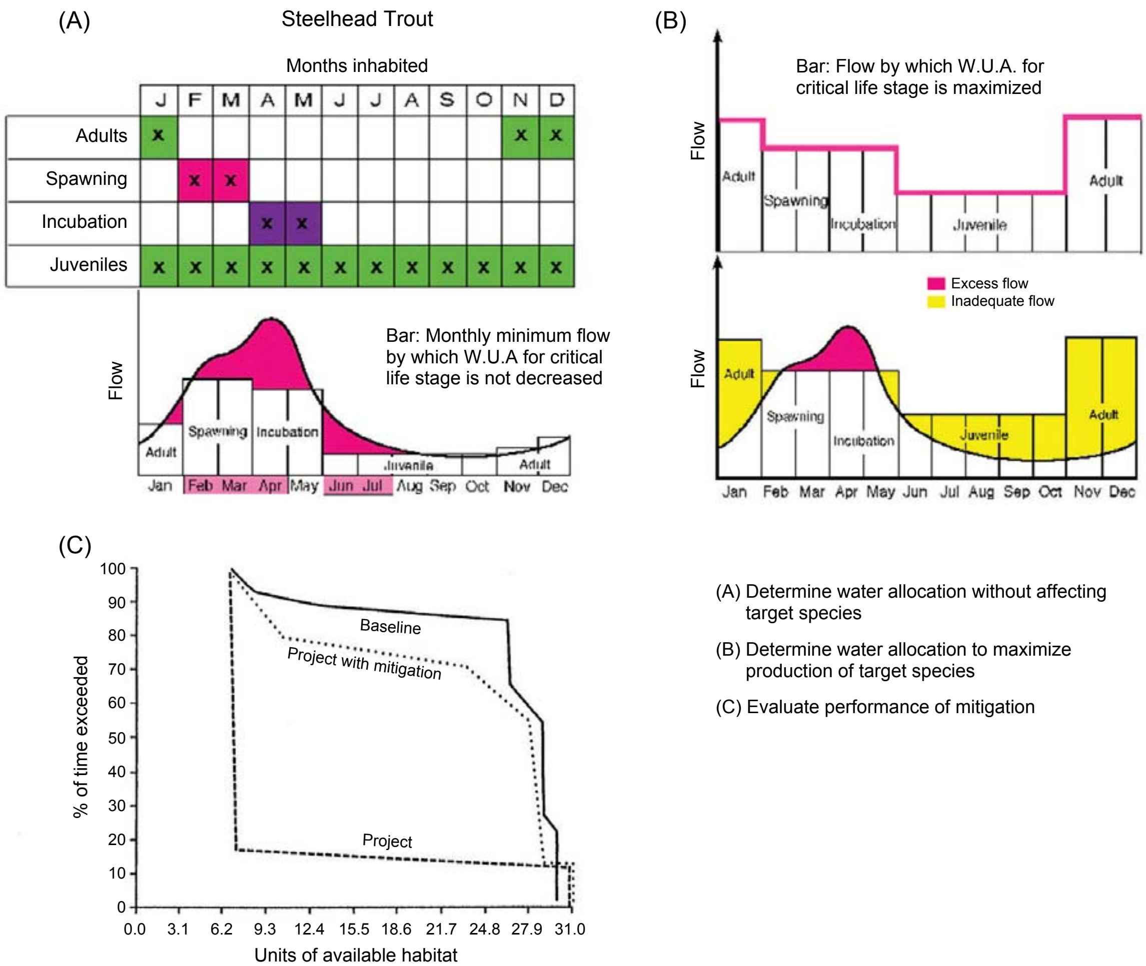


Fig. 5. Some examples of evaluation using habitat time series. (A) Upper table shows critical life stage of steelhead trout in each month. Bars in lower figure shows monthly minimum flow by which WUA for critical life stage is not decreased. Curved line in the figure shows hydrograph of the river. Colored area between hydrograph and bars shows water volume which can be taken from the river without affecting the fish. Based on this figure, decision makers may give permission of taking water to encourage manufacturing industry. (B) Bars in upper figure show flow by which WUA for critical life stage is maximized. In lower figure, the bars and hydrograph are overlaid. Light colored area between the bars and hydrograph shows shortage of water volume for optimal habitat condition. Dark colored area between hydrograph and the bars shows water volume which can be taken from the river without affecting the optimal habitat. Based on this figure, decision makers may keep water in a dam from February to April and release it in November and December to help fishery. (C) In current condition, 25 units of habitat exist almost 90% of whole year period (Baseline). When a project completed, only 7 units of habitat will exist 90% of a year, and 8 units of habitat can be achieved only 15% of a year (Project). When mitigation is done, 23 units of habitat remain 70% of a year (Project with mitigation). Decision maker may use this information to give permission to the project. (A) and (B) were taken from USGS homepage in 1996 (removed). (C) was taken from Stalnaker *et al.* (1995).

engineers who didn't know much about living organisms.

Under such circumstances, IFIM/PHABSIM was introduced to Japan by Nakamura in 1994. IFIM/PHABSIM was expected as something introducing numerical, quantitative method into designing "fish friendly" rivers, and a lot of studies were conducted. Because the concept of PHABSIM was simple, most of them didn't use PHABSIM software but employ similar habitat calculations by themselves. In spite of the effort of Nakamura (1999) to introduce correct idea of IFIM, situation had not been much changed, and criticism to the accuracy of habitat calculation and applicability to different rivers arose without understanding the researches in the US. This might be partly because the language barrier, and also because the needs to this method was limited. In Japan, we don't have any legal incentive to employ IFIM because our environmental impact assessment law doesn't request us to have quantitative evaluation of alternatives even now. Some efforts exist to introduce correct usage of PHABSIM, for example, by Sekine (2006), and a stream for firefly was constructed by Yamaguchi prefectural government based on PHABSIM evaluation by Sekine (2007). Currently, many people in river management field of Japan know the name of PHABSIM (not IFIM), but not many actively want to use it. Only some decision makers notice the applicability of this method to some limited species. Also some consultant companies use PHABSIM-like habitat calculation in their designing stage, but those are mainly for in-company use, and don't appear explicitly in designing and/or planning reports. Japanese people tend to care about protecting biological diversity rather than protecting specific target species, and this tendency also may lower the popularity of this method.

In spite of above mentioned situation, there exists a possibility of raising a big problem in river management which needs extensive negotiation in Japan. In reality, such problem has already been occurred like the case of Kawabe river in Kumamoto prefecture which took 43 years' dispute after the project started. I believe IFIM is a useful methodology to solve river related problems, and Japanese people need to prepare for applying it to such a big problem. For this purpose, much more trial use of IFIM/PHABSIM to smaller projects should be needed to acquire experience of applying it. Correct understanding through such experiences is essential for wide acceptance of this useful methodology.

DISCUSSION

After presenting this paper in International Symposium on Aquatic Ecosystem Health Enhancement held in Daegu, Korea in 2011, I learned about the mega-construction project in four big rivers including Nakdong river. I understand the situation where Korean people are hurrying to prepare for a possible change of ecosystem in the river. Since the weirs have already been almost completed, ecosystem changes should have already been started.

I suggest that the strategies Korean people might take be like below:

1. Determine a preliminary water release procedure from the weirs which will be most probably harmless to the original ecosystem as soon as possible. After that, or at the same time, you might continue more detailed research to determine a reliable environmental protection program.
2. Conduct a survey to understand the original ecosystem condition while it is still remaining.

To accomplish the point 1, IFIM/PHABSIM is the most suitable method, I think. IFIM/PHABSIM is a diagnostic tool which directly connects between controllable physical variables and living organisms. And the current project, which is something controlling water release by weirs, is most suitable subject to IFIM/PHABSIM. You can evaluate the change of WUA for important species caused by the change of water release. Then you can determine appropriate water release to protect the ecosystem, to maximize ecosystem health, or to minimize hazardous effect of project on living organisms.

You may think that determining HSIs needs intensive research. But there are some other ways to determine HSIs with inexpensive method. If you need to define HSIs without intensive surveys, you may ask fish authorities through questionnaire like Delphi method. Although the HSIs determined through such method may not fit for negotiation, they could serve for quick decision of a preliminary water release procedure.

To accomplish the point 2, you would at least need to have data of water level, flow rate, and velocity distributions of before and after project, together with cross section geometry. These data would also be important when you verify/validate model outputs. The data of living organisms are already taken within your nationwide research project, I believe. If you are also collecting physical habitat data of velocity, depth, and substrate at the location where living organisms are found, it would be perfect. Even when you are not collecting the physical habitat data, data of living organisms are extremely important to understand the original ecosystem to be protected.

Quick action would be essential to protect Nakdong and other river environments.

CONCLUSIONS

Overview and history of Instream Flow Incremental Methodology (IFIM) are described together with current situation of usage in the U.S. and Japan. Based on this information, prescription for mega-construction project in four big rivers is discussed.

Although the basic concept of evaluating habitat condition in IFIM is rather simple, the simplicity has caused a lot of misuse of it. Good understanding and careful application of the methodology is essential. This paper intended to give a correct understanding of IFIM in as short format as possible. Readers who want to apply IFIM to real projects should refer original articles.

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