SUITABILITY CRITERIA FOR ASSESSMENT OF INSTREAM FLOW NEEDS OF FISH

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Increased water use to support population growth and expanding economic development throughout the United States has brought about a corresponding demand for stream water (Leonard et al. 1986). In the western portion of the United States, competition for stream water has often been fierce (Frederick 1982; Weatherford 1982). Water resource management agencies in the southeastern United States (Southeast), where water has been relatively abundant, are now being faced with similar competing demands for water, and with increasing pressures to develop and defend recommendations for protecting fish and invertebrates in streams. Streamflow depletion at any time can result in severe long-term effects on fish populations (Peters 1982). Consumptive water use nationwide is expected to increase 27% by the year 2000 (U.S. Water Resources Council 1978), and conflicts between instream and offstream uses of water will probably become increasingly acute in the Southeast.

Fishing, boating, wading, and swimming are some valuable uses of water flowing in a stream (i.e., instream flow). Other valuable uses are waste assimilation, navigation, maintenance of channel form and bed material characteristics, and hydropower. Industrial and domestic water supplies, irrigation, and generation of electricity are major offstream uses that have long been recognized as valuable. The allocation of stream water to any of these instream or offstream uses is tied to the issues of water quantity, quality, and timing, which center on two critical questions: When and how much water of an acceptable quality should be left in a stream and What happens if flow regimes are changed? Answers to these questions will probably be complex, but reliable answers are needed to protect instream and offstream values. Just as complex as the technical components of these questions are the political, legal, and institutional frameworks for implementing stream water allocation programs (Wilds 1986). However, if instream flow interests expect to compete with offstream uses for limited water supplies, they must be able to establish reliable and defensible methods for determining instream flow needs and demonstrate the environmental consequences of altered flow regimes (Allred 1976).

My objectives here are: (a) to present an overview of the need, development, and use of stream habitat suitability criteria, and the use of these criteria for the assessment of instream flow needs; (b) to give a status report on the plan of the National Ecology Research Center (NERC) for expansion of instream flow research in the Southeast; and (c) to discuss the relevancy of the research to river corridor management.

Stream Habitat Suitability Criteria and Evaluation Methods

The need for stream habitat criteria and methods useful for evaluating instream flow values for fishery resources was first recognized in the western United States during the 1950's and 1960's (e.g., see Trihey and Stalnaker 1985). By 1982, instream flow programs of some sort were maintained by 22 states (Lamb and Meshorer 1983). As instream uses and values became more widely recognized and competition for water grew, many useful methods evolved for identifying, evaluating, recommending, and managing instream flows (Arnette 1976; Tennant 1976; Stalnaker 1978; Wesche and Rechard 1980; Loar and Sale 1981; Newcomb 1981; Trihey and Stalnaker 1985; Filipek et al. 1987; Jacobs et al. 1987).

Methods for evaluating instream flow needs are in two general categories: (1) "standard-setting" or threshold, and (2) "incremental" (Trihey and Stalnaker 1985; Leonard et al. 1986). Standard setting refers to the measurements and interpretive techniques designed to generate a flow recommendation that is intended to maintain the fishery at some acceptable level. Most of the instream flow evaluation methods developed to date are standard-setting. However, standard-setting methods yield threshold or single-flow recommendations, and have only limited ability to incorporate biological or hydrological information. The methods may be useful for setting flow standards in many situations but are not designed to answer an important question: What happens to the fishery habitat if the streamflow (standard) identified for maintaining the fishery habitat is not delivered? This question can usually be answered best by the incremental approach.

The incremental approach for evaluating instream flow needs of fish evolved in the western United States for coldwater species (Collins et al. 1972; Dooley 1976; Issacson 1976; Waters 1976; Bovee 1978). The synthesis and refinement of these and other concepts led to the development of the Instream Flow Incremental Methodology or IFIM (Stalnaker 1979; Orth and Maughan 1982; Bovee 1986). This habitat-based, state-of-the-art methodology has been widely applied for evaluating instream flow needs for coldwater fishes. It has been applied on a more limited basis to evaluate instream flow needs for benthic macroinvertebrates (Gore 1978; Gore and Juday 1981; Orth and Maughan 1983), to evaluate water contact recreational activities (Hyra 1978; Fritschen et al. 1984; Mosely 1983), and to preserve dinosaur tracks (Spain 1987).

The implementation of a "complete" IFIM analysis requires several sets of data and models (Figure 1). Prerequisite and probably the single greatest constraint to applying the IFIM is knowledge of the microhabitat preferences or suitability of the species targeted for evaluation. This information is usually presented in the form of habitat suitability criteria or Suitability Index (SI) curves (Bovee 1986). The suitability range of a particular variable in microhabitat is assigned weighting factors or SI's ranging from zero to one. Optimum habitat is assigned a value of one and unsuitable habitat a value of zero; habitats of intermediate suitability indexes are represented by intermediate habitat suitability values. The SI curves are used with the Physical Habitat Simulation System (PHABSIM) of Stalnaker (1979), Bovee (1982), and Milhous et al. (1984) to compute habitat availability under various simulated flow regimes. The physical models within PHABSIM describe how the environment changes with respect to streamflow and translates streamflow to weighted usable area of habitat (Figure 2). This translation enables quantification of the amount of potential habitat available for a species and life history phase in a given reach of stream under various flow regimes, and the development of habitat time series (Figure 3). One underlying assumption of the IFIM is that there is a positive, linear relation between the weighted usable area of habitat for the controlling life stage and the standing stock of the fish species being evaluated. This underlying assumption of IFIM (and some others) have not been validated to the satisfaction of some critics (Mathur et al. 1985; Granholm et al. 1985; Shirvell 1986). Nevertheless, IFIM has been shown to be a defensible technique for adjudicating flow regimes needed to support fish populations and to maintain other identified instream values at desired levels--particularly for western United States streams dominated by snowmelt hydrology and salmonid fishes (Sweetman 1980; Cavendish and Duncan 1986; Garn 1986; Gore and Nestler 1988; Bovee, in prep.; Nehring and Anderson, in prep.).

Stream Impact Assessment in the Southeast

The strength of IFIM lies in its ability to estimate the effects of various flow regimes on fish habitat when habitat suitability for the species of concern is known (Orth and Maughan 1982). In spite of this strength and its wide application in coldwater streams, IFIM has not received high acceptance for use in warmwater streams; the reasons probably include the high species diversity (McAllister et al. 1986; Starns and Etnier 1986; Swift et al. 1986) and lack of SI curves for many of the species, and fundamental differences in warmwater and coldwater fish communities (Bain 1988). Additionally, practical information on measuring streamflows in large streams is relatively scarce (Knudsen et al. 1984) and methods for the accurate identification and measurement of fish habitat in large, deep streams challenges the methods conventionally used (Larimore and Garrels 1985).

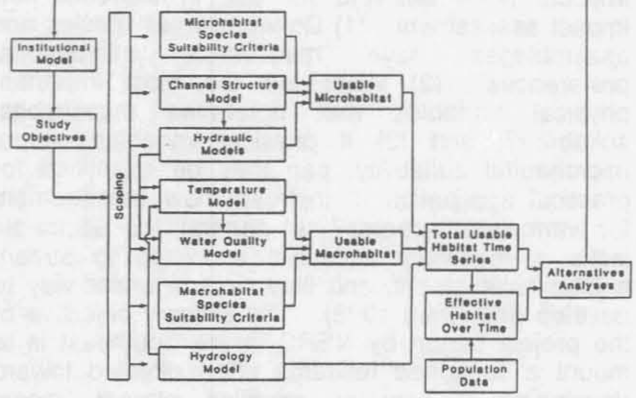

Figure 1. Components of the Instream Flow Incremental Methodology (IFIM).

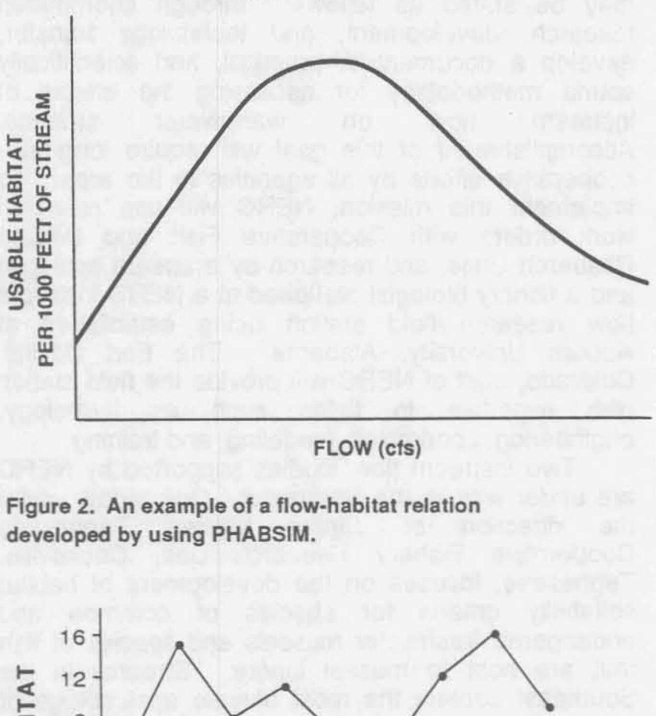

Figure 2. An example of a flow-habitat relation developed by using PHABSIM.

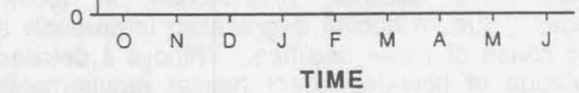

Figure 3. An example of a habitat-time relation developed by using IFIM.

As judged from surveys conducted by the Aquatic Systems Branch of NERC, the most important issue related to the effects of instream flow expected in the Southeast over the next decade will result from new hydropower development, the relicensing of existing hydropower facilities, and water navigation projects. Rapid fluctuation of flows, periodic dewatering, major reductions in streamflow, and reduced habitat quality and quantity for riverine species are expected to be caused by such projects. Three critical questions related to these anticipated impacts need answers for use in instream flow impact assessment: (1) Do warmwater species and assemblages have measurable microhabitat preferences?; (2) What are the most important physical variables that determine microhabitat suitability?; and (3) If physical variables control microhabitat suitability, can they be quantified for practical application in instream flow management for warmwater streams? In general, the Southeast lacks a regionally accepted approach to stream habitat assessment, and little work is under way to develop one (Bain 1988). The primary objective of the project begun by NERC in the Southeast is to mount a sustained research effort directed toward developing a new or modified stream impact assessment approach acceptable for use in warmwater streams of the area. The overall goal may be stated as follows: through coordinated research, development, and technology transfer, develop a documented, practical, and scientifically sound methodology for assessing the effects of instream flow on warmwater streams. Accomplishment of this goal will require long-term cooperative efforts by all agencies in the area. To implement this mission, NERC will use research work orders with Cooperative Fish and Wildlife Research Units, and research by a stream ecologist and a fishery biologist stationed at a NERC instream flow research field station being established at Auburn University, Alabama. The Fort Collins, Colorado, staff of NERC will provide the field station with expertise in fields such as hydrology, engineering, economics, modeling, and training.

Two instream flow studies supported by NERC are under way in the Southeast. One study, under the direction of James Layzer, Tennessee Cooperative Fishery Research Unit, Cookeville, Tennessee, focuses on the development of habitat suitability criteria for species of common and endangered freshwater mussels and species of fish that are host to mussel larvae. Streams in the Southeast contain the most diverse assemblage of freshwater mussels in the world. Several species have become extinct and populations of other species have declined precipitously in recent decades. Stream habitat degradation is probably a major cause of these declines. Without a detailed knowledge of flow-dependent habitat requirements for mussels and their host fish species, resource agencies are hampered in providing defensible instream flow recommendations for the protection and enhancement of mussel populations. This mussel study was started in mid-1988 and is to end in 1991. Major field work is under way in the upper Cumberland River basin in Tennessee and Kentucky. An extensive review of the literature on life histories and ecological relations of mussels in the area has been completed (Layzer, in press).

The second instream flow study currently being supported by NERC in the Southeast is being conducted under the direction of Mark Bain, Alabama Cooperative Fish and Wildlife Research Unit, Auburn University, Alabama. This study focuses on the determination of relations between warmwater stream habitats, flow regimes, and fish communities, and on the development of new or modified stream impact assessment approaches for warmwater streams. The study involved two initial tasks: (1) conduct a literature review on regulated streamflow and warmwater stream fish communities, and (2) develop a general hypothesis of the effects of regulated flow on fishes and invertebrates; this hypothesis will be a framework for designing and conducting a sequence of steps and tests directed toward developing a documented and generalized model of the effects of flow regulation on warmwater stream fishes and aquatic invertebrates. Detailed results of these two completed tasks are available (Bain 1988). A concise statement of the general hypothesis that was developed follows: highly regulated streamflow regimes will change fish and invertebrate biomass and species composition differently in shoreline and midstream habitats, and the extent of change depends on the characteristics of the physical habitat and flow regime. This general hypothesis suggests that a stream habitat assessment method can be developed that requires less precise and intensive habitat modeling than that commonly used in the IFIM, and still be predictive, quantitative, and biologically justified. Sampling sites for this study are to be in the Alabama River basin. Field work was started in 1988 and the study is to end in 1993.

Stream Fisheries and Concomitant Wetlands

A secondary objective of the NERC field station established at Auburn will be to identify and quantify functional relations between stream corridor fisheries and concomitant forested palustrine wetlands. Riparian wetlands that flank many of the major streams in the Southeast are coupled to river corridors by way of a "water bridge," at least during flooding. It is generally known but not sufficiently quantified or substantiated, that such wetlands provide spawning, feeding, and cover habitat for many fish species (Welcomme 1979; Wharton and Brinson 1979; Wharton 1980; Wharton et al. 1981); they also import, store, produce, and recycle materials used in food chains in situ by numerous organisms, including fish (Day et al. 1977, 1980;

Livingston and Loucks 1979; Conner and Day 1982). Furthermore, some residual materials are exported from the wetlands to downstream aquatic systems where the materials are available for use in food chains (Figure 4). These riparian wetlands exist as a result of hydrologic regimes (Gosselink and Turner 1978; Brinson et al. 1981; Klimas 1988). The timing, magnitude, and duration of flooding are primary determinants of the wetland's structure and function (Gosselink and Turner 1978), but these variables have not been sufficiently quantified relative to fish habitat suitability (Crance 1988). A better understanding of the relations between streamflows and hydrologic regimes required for the well-being of palustrine-related fisheries will provide information useful for the management of river corridor resources.

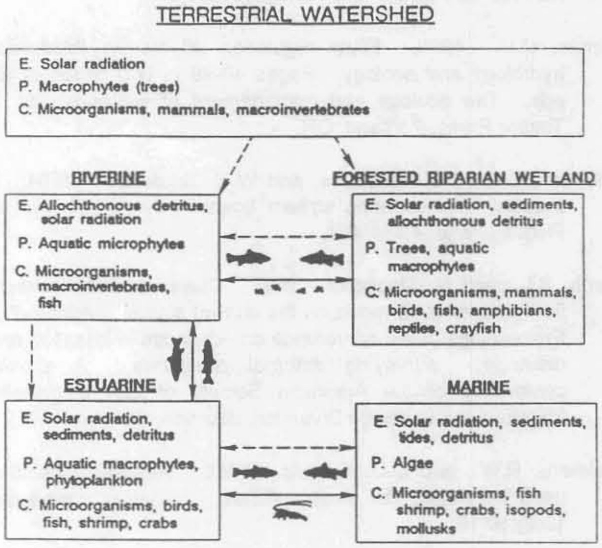

Figure 4. Terrestrial Watershed

Schema showing the potential for transfer of materials between a palustrine wetland of a forested riparian floodplain and other systems linked directly or indirectly to the wetland for each system, examples are given of major sources of energy (E), some major primary producers (P), and some major consumers (C). An arrow with a broken line indicates direct linkage and the direction of transfer of water, detritus, nutrients, and sediments. An arrow with a solid line indicates direct linkage and direction of movement of fish and other primary consumers. From Crance (1988).

Conclusion

The goals of the instream flow research supported by NERC in the Southeast is broad but does not cover all potentially important mechanisms affecting stream fish and invertebrates. Water quality, stream bed substrate patterns, channel morphology, fish migration patterns, and food supply may be affected adversely by various watershed and stream developments. Information about habitat use and requirements by larval fish in warmwater streams is inadequate. Bain (1988) reviewed research that contrasted coldwater and warmwater stream systems and surmised that the distinction may be between headwater streams and large main-stem streams. Almost all research on headwater streams has been done in coldwater streams, but the Southeast has many small, steep, warmwater streams. Research on these systems would enhance current research and understanding of fish-habitat relations in different stream systems of the Southeast.

Significant advances in assessing instream flow assessment have been made over the past several decades, but much more research is needed to advance the state of the art, especially for warmwater streams. It is to be hoped that research begun by NERC in the Southeast will provide some of the criteria needed for the evaluation and protection of instream flows and will serve as a stimulus for more comprehensive and cooperative research in warmwater stream ecology in this region.

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