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United States Department of the Interior

FISH AND WILDLIFE SERVICE
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January 30, 2003

Angela Risdon
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Dear Ms. Risdon:

Subject: Kilarc-Cow Hydroelectric Project, FERC No. 606, Shasta County, California - Comments on the First Stage Consultation Package

This responds to the Pacific Gas and Electric Company's (PG&E) June 24, 2002, letter to the U.S. Fish and Wildlife Service (Service) which transmitted the First Stage Consultation Package (FSCP) in preparation for filing an application for new license for the Kilarc-Cow Hydroelectric Project (Project). Comments were due back to PG&E (Applicant) on or before October 7, 2002. For various reasons, PG&E extended the comment period until November 6, 2002. The Energy Planning and Instream Flow Branch of the Sacramento Fish and Wildlife Office has recently undergone several staff changes and no comments were sent in response to the FSCP by the November 6, 2002 deadline. The Service realizes that the deadline for submitting comments has passed; however, PG&E has agreed to accept Service comments submitted after the extended deadline. We appreciate this opportunity to comment on the FSCP.

Introductory Comments on the 1st Stage Consultation Process

The Kilarc-Cow Project is a multi-dam hydroelectric project encompassing the Old Cow Creek and South Cow Creek Watersheds, including Mill Creek and North and South Canyon Creeks. There is existing data from previously completed studies, as well as new concepts about the management of river systems, that support the development of additional studies to describe and evaluate resources within the project affected area.

The purpose of these comments is to define data needs and study requirements so that sufficient information is provided in the Final Application for new License (FAL) to foster the development of Service recommendations that will adequately protect, mitigate, and enhance fish and wildlife populations and overall ecosystem health. Specifically, the Service desires to: (1)

provide better technical information for sound resource decisions, (2) reduce time necessary for settling disputes, (3) more effectively address stakeholder needs, and (4) provide greater stakeholder satisfaction.

The Service has not been able to fully participate in collaborative meetings; however, we wish to emphasize that the collaborative process is valuable in that it helps us identify topics of resource concern, evaluate the usefulness of previous studies and existing data, and develop effective final study recommendations.

General Comments

The FSCP provides a good overview of project facilities and operations, the surrounding area affected by the project, and the fish and wildlife resources that occur within the project area. While most of our major areas of concern are addressed in the document, we note that study design deficiencies, as studies are described in the study plan, may result in inadequate studies and inconclusive study results. Ultimately, the data provided from the studies must be sufficient to satisfy the Service's needs to make determinations about the protection of general fish and wildlife resources, federally listed threatened and endangered species, species of concern, and the Commission's evidentiary record to support its licensing determination.

The Service's participation in licensing this project is aimed at representing our: 1) procedural interests to ensure applicant and agency compliance with the Fish and Wildlife Coordination Act, Endangered Species Act (ESA), Federal Power Act, National Environmental Policy Act and other Service legal mandates and authorities, and 2) our substantive mission-related interests; for example, conservation of fish and wildlife populations and their habitat, restoration of ecosystem functions, structure and composition, and fulfilling trust responsibilities for anadromous fish, migratory waterfowl, wetlands, riparian habitat, and threatened and endangered species.

We plan to use an ecosystem approach for evaluating the effects of licensing this hydroelectric project. Our goal is to protect, maintain and, if necessary, restore the stream reaches within the Project affected area to a self-sustaining fully functional ecosystem with structure that supports all life stages of naturally occurring species, recognizing that all physical, chemical and biological components are interrelated. We will examine the impacts of ongoing project operations and maintenance, and evaluate potential mitigation and enhancement measures.

The area surrounding and within the project boundaries is comprised of a variety of fish and wildlife, their habitats, recreational areas, project features and cultural resources. To facilitate understanding and to address a relatively complex variety of data needs, we divide the ecosystem into compartments, also known as metrics, and examine measurable compartmental indicators. General compartments can include but are not limited to: Project operation, water quality, geomorphology, sediment transport and deposition, historic unimpaired and existing hydrology, riparian condition, wildlife, fisheries and aquatic health, and total habitat area.

Specific Comments

Proposed Studies and Methodologies: The following comments are in regard to the study plans listed in the FSCP. The Service understands that all studies, as proposed, are to be completed in 2003.

Hydrology. Section 6.1.1

The Service's objective for the hydrologic attribute is to develop an instream flow regime that is patterned after the unimpaired hydrograph with similar patterns of flow magnitude, duration, frequency, timing and rates of change. By improving components of the hydrograph currently impaired by the Projects, we believe the essential ecosystem attributes of the watershed can be conserved, enhanced, and restored. Therefore, the Service requires "impaired' and "unimpaired" hydrologic information to assess the effects of Project developments and operations on the hydrology in riverine bypass reaches. The effects of tributaries and diversions are important to the entire project area influencing the flow and temperature regimes in the mainstem. Therefore, seasonal tributary and canal flows should be measured. The locations of gages where flow data has been or is to be taken should be displayed on a map to facilitate interpretation. The Service recommends that the Applicant categorize various water supply years (e.g. wet, normal, dry, critically dry, etc.) to allow for a more refined incremental approach to water supply allocation, thus reducing the potential for adverse consequences to aquatic habitat and biota.

Water Quality. Section 6.1.2

Water Quality measurements in the Project reaches, canals, and reservoirs can be used to assess project impacts on the ecosystem, compliance with the State Water Resources Control Board's (SWRCB) Water Quality Control Plan for the Sacramento River and San Joaquin River Basins (Basin Plan) criteria and beneficial use identification. These measurements serve as chemical indicators that assist the Service in accomplishing its goal of making sound biological decisions that will protect, mitigate, and enhance water quality conditions for fish and wildlife species that inhabit or utilize waters in Project-affected riverine reaches. Meaningful results depend on appropriate seasonal timing, location and frequency of data collection. The PG&E has proposed a one-year water quality study in 2003 under existing release conditions with two samples (once during winter months and once in the summer months) to be taken at each of six locations in Old Cow Creek and six locations in South Cow Creek. While winter and summer months may represent very general differences in flow conditions; as proposed, it is likely that data from this study will provide little information regarding the chemical patterns (including constituent maxima and minima) or overall Project effects on water quality in Project-affected riverine reaches.

The Service recommends the frequency of monitoring be increased to once per month, except for in critical summer months (July-September) when sampling should take place every two weeks, with the exception of trace metals scans which should be taken monthly. We concur with most of the specific constituents to be measured, but we also recommend that barium, cadmium, cyanide, and silver concentrations be measured (and included in Table 6.1-1 of the FSCP) since specific maximum concentrations are listed in the SWRCB's Basin Plan for the Sacramento River. The specific sampling locations were not clear in the FSCP; therefore, no specific comments can be made concerning these sites. The Service does expect; however, that sampling locations will be chosen to best represent the water quality in the entire Project area and the potential impacts of Project operations and facilities. For example, samples should be taken both immediately upstream and downstream of dams, tributaries, and powerhouse tailraces.

For in-situ water quality measurements (pH, dissolved oxygen, air and water temperature, conductivity, and turbidity), a single sample taken in the summer months will not be sufficient. During the critical summer months (July-September), it is particularly important that water temperatures, pH and dissolved oxygen (DO) levels do not deviate beyond limits imposed by the SWRCB's Basin Plan for cold freshwater habitat. This would require that bi-daily or even hourly measurements be taken during these critical periods. The hourly recorders proposed for temperature monitoring in section 6.1.3 are intended to satisfy the need for temperature monitoring during critical periods; however, the effects of Project developments and operations on the daily maxima and minima of the remaining aforementioned measurements should also be assessed during these critical periods. A map indicating the precise locations of all sample sites in relation to natural and constructed physical features including dams, diversions, powerhouses, tributaries, etc. will aid the interpretation of the data. The Applicant should consult with resource agencies to coordinate more meaningful water quality studies.

Water Temperature. Section 6.1.3

Water temperature is critically important in determining abundance and distribution of aquatic biota because it greatly affects metabolic and growth rates. It also appreciably affects other water quality variables, such as dissolved oxygen concentrations, which are biologically significant. The Service's objective for water quality is to develop an instream flow regime that provides water quality conditions at all times of the year that (at minimum) meet SWRCB standards as prescribed in the Basin Plan. According to the Basin Plan, the Project area is to be managed as cold freshwater habitat and as both warm and cold freshwater spawning habitat. The Service believes that ensuring Basin Plan temperature criteria are met is the first step toward accomplishing its goal of protecting, mitigating, and enhancing fish and wildlife populations that inhabit or utilize Project-affected waters. The Service requires "impaired" and "unimpaired" temperature information to assess the effects of Project developments and operations on temperature regimes in all Project-affected aquatic habitats. Water temperature regimes are characterized by temperature magnitude, duration, frequency, seasonal timing, daily ranges, and rate of change. To determine whether Basin Plan criteria are met, the Applicant plans to monitor water temperatures during the months of July, August, and September in 2003. The Service maintains that meaningful results depend on appropriate seasonal timing, location and frequency of data collection. The Service is generally pleased that the Applicant has developed a temperature monitoring plan. We recommend that temperatures be measured both immediately upstream and downstream of all dams, powerhouses, and tributaries to better elucidate the potential effects that Project developments and operations may have on instream temperatures and whether water temperatures are within the limits required by the SWRCB's Basin Plan. The Service also suggests that temperatures be plotted at a fine scale (e.g. hourly) to aid the interpretation of the biological significance of these data.

Sediment. Section 6.1.4

The Applicant plans to conduct a qualitative study of the sediment supply and transport characteristics in the Project-affected riverine reaches. While a qualitative description may be somewhat informative, quantitative information that is flow-related is the most useful in developing effective flow recommendations. Therefore, we recommend that sediment supply and transport be studied quantitatively and that a flow relationship be developed describing the flows necessary to transport fines, sands, and gravels in riverine reaches. The study should specifically assess how project developments and operations affect the supply and transport of sediments in riverine bypass reaches.

Smaller magnitude flood pulse events and freshets, although infrequent, are expected and important elements of the unimpaired hydrographs of California rivers and streams. The containment of such pulse flows by dams and diversions are likely to result in changes to micro-scale in-channel sediment storage dynamics. When changes in storage dynamics are combined with a decrease in sediment supply (also due to dams), textural changes in stream bed composition are likely to occur. These changes may adversely affect aquatic species (e.g. salmonids and macroinvertebrates) that depend on sediments with specific qualities during various life stages.

Aquatic Habitat Mapping. Section 6.3.1

The Applicant plans to study and map aquatic habitats. The Service generally agrees with the Applicant's proposed substrate classifications; however, we recommend that "gravels" (2-64 mm sediments) be categorized into specific spawning-sized gravels with dimensions and characteristics suitable for rainbow trout, steelhead, and Chinook salmon spawning (e.g. 0.25-1, 1-3, and 1-4 in. gravels, respectively). This additional classification will facilitate the interpretation of aquatic habitat data and the development of effective protection, mitigation, and enhancement (PM&E) measures for salmonid species.

Passage Barrier Identification. Section 6.3.2

The applicant plans to survey and map potential fish passage barriers in the riverine bypass reaches. Along with these data, the Service requests that the applicant provide specific definitions (and rationale) for "low," "medium," and "high" flows as well as for "partial" and "complete" barriers to fish passage. As presented in the FSCP, the Applicant's Passage Barrier Survey plan is too general for the Service to comment on its sufficiency. For example, statements such as "size will be evaluated" are too vague for evaluation. The Applicant should consult with the National Marine Fisheries Service (NMFS), Service and other appropriate resource agencies to develop effective methods of measuring and validating the severity of each fish passage barrier under a variety of flow conditions.

Instream Flow Study (PHABSIM). Section 6.3.3

The Applicant plans to conduct Instream Flow Incremental Methodology studies within riverine bypass reaches. IFIM is one analytical tool for making instream flow recommendations. Since on-site development of habitat suitability curves (HSCs) provides for more accurate predictions, the Service suggests that the Applicant develop site-specific HSCs for each flow relationship to be modeled. As presented in the FSCP, IFIM studies are only intended to develop flow-habitat relationships for fish and macroinvertebrates. Investigation and subsequent integration of multiple ecosystem attribute relationships can be an extremely useful tool for making sound biological decisions for complex ecosystems. An integrated instream flow study should not be limited to flow-fish or flow-macroinvertebrate habitat relationships, but should also assess other flow-related relationships such as: 1) stage-discharge relationships for riparian inundation and amphibian breeding area; 2) flow-sediment relationships; 3) flow-temperature relationships; and 4) flow-recreation relationships. In addition, other riverine resources or attributes for which a flow-based relationship could be developed and used to make effective instream flow recommendations should be examined by technical working groups and reported as part of the instream flow study. This type of integration will assist the resource agencies and other stakeholders in jointly developing a flow regime that will effectively protect, mitigate, and enhance the riverine ecosystem and its functions.

Fish Population Studies. Section 6.3.4

The Applicant's fish sampling methods as proposed in the FSCP are generally acceptable; however, the Service has some suggestions to improve the usefulness of the acquired data. First, sampling methods should be standardized so that data can be compared and contrasted between sample sites. For example, the Applicant should not measure "total length or fork length" for each fish, but should measure both lengths so the data can easily be compared between sample sites or a regression can be run to convert fork length measurements to total lengths for analysis. Also, the Applicant should calculate and analyze the condition factor (an indicator of health) of each juvenile and older salmonid collected. The FSCP does not specifically indicate the locations where fish will be sampled. The Service suggests that fish be sampled in riverine reaches both immediately above and below dams, tributaries, tailraces, and in the Project canals, forebays and lakes. The methods used should be standardized (when feasible) so that population estimates can be compared between sampling sites. For example, snorkel surveys should be conducted prior to electrofishing in Old Cow Creek and North and South Canyon Creeks so that comparisons can be made between fish populations in these reaches as well as those where anadromous salmonids may be present and no electrofishing is to be conducted (e.g. South Cow Creek). The Service does not concur with the fish subsampling methods as proposed in the FSCP. First, 10 fish per 25-mm class may be too few to obtain a good representation of the sample. Instead, 20 fish within each size class would be more informative and the methods of subsampling should produce a random subsample, representative of the original sample. Also, we expect that the total number of fish collected within each size class will be counted and recorded so that a weighted length-frequency distribution can be developed to characterize the population structure. The Applicant should also provide a list of all native and non-native species that may potentially occur in the Project-affected area along with a list of all species collected and observed during 2003 fish surveys.

As part of the fish population study, the Applicant plans to make "general observations" of habitat and physical conditions in the sampling stations including water temperature, specific conductance, DO, substrate type, depth, riparian conditions, and the presence of woody debris and cover. The Service recommends that the Applicant make "specific observations" that are quantitative and descriptive so that it can develop site-specific HSCs that will improve the accuracy of IFIM fish habitat modeling. The Applicant should consult with the Service if it needs further clarification regarding the information required for the development of effective site-specific HSCs.

Entrainment. Sections 6.3.5 and 6.3.7.1

The Service intends to exercise its authority to prescribe fish protection facilities (for salmonid species) pursuant to Section 18 of the Federal Power Act by reserving that authority when the Application for New License is ready for environmental analysis. Any future decision to invoke this prescription authority will in part depend on the adequacy of information and analysis developed during the study period. Section 6.3.5 of the FSCP is designed to help describe the potential fish entrainment through the Kilarc powerhouse. Section 6.3.7.1 is intended to describe the efficacy of fish screens that are currently in place on South Cow Creek. We are pleased that studies are to be conducted and analysis made to determine if there are significant project impacts on fish populations due to entrainment at the project facilities. The extent of information needed and final specific study designs should be developed through consultation with resource agencies.

Project Effect on Macroinvertebrates. Section 6.3.6

One measure of stream health, as an integral part of the riverine ecosystem, is the state of its macroinvertebrate communities. The Service is pleased that the Applicant plans to evaluate potential habitat for this metric using the PHABSIM methodology. While flow-habitat models are useful in developing instream flow requirements, they can only complement other studies yielding information regarding the distributions and abundances of fish and other aquatic biota. Also, on-site development of HSCs results in more accurate predictions, especially for benthic macroinvertebrates since community composition varies from system to system (Gore *et al.*, 2001). Therefore, the Service recommends that PG&E conduct macroinvertebrate surveys to determine the composition and abundances of macroinvertebrate communities throughout the Project-affected area and to develop site-specific macroinvertebrate HSCs. Developing a flow-biomass relationship for macroinvertebrates may also prove useful for determining the effect various flows have on local populations. The details for macroinvertebrate studies should be determined through coordination and consensus of the Applicant, California Department of Fish and Game (CDFG), NMFS and the Service.

Sensitive Aquatic Species. Section 6.3.7

The FSCP only indicates fall-run Chinook salmon and steelhead as sensitive aquatic species that occur in the Project-affected area. The Applicant should also evaluate potential habitat for other sensitive species that may occur in the Project-affected area, especially spring-run Chinook salmon. Fish population studies, fish passage barrier studies, and IFIM studies will aid in the development of PM&E measures for sensitive aquatic species found in the Project-affected area. The Applicant should consult with the CDFG, NMFS, and Service concerning any sensitive aquatic species issues.

Threatened and Endangered Species

The Service has provided guidance to the PG&E during this 1st Stage Consultation process regarding information and analysis that will be necessary to ensure compliance with the Endangered Species Act of 1973, as amended, at a meeting held on May 3, 2002 at ENTRIX, Inc. The Service provided PG&E with a species list. The meeting included the development of studies and survey protocols for appropriate species of interest to the Service. We also provided PG&E with additional information since that meeting regarding the threatened northern spotted owl *(Strix occidentalis caurina)* and the threatened bald eagle (*Haliaeetus leucocephalus*).

Wildlife Studies. Section 6.4.

6.4.1 and 6.4.2 Common and special-status wildlife surveys

Bald eagle and peregrine falcon surveys are to be conducted in the immediate project vicinity and are to be conducted a minimum of two times during the 2003 raptor breeding season. Bald eagle surveys should be concentrated at areas where the bald eagles have been observed perching in the past, (near the Kilarc Forebay), and conducted in the early morning hours when bald eagles are known to be foraging. PG&E should conduct these surveys at a frequency greater than two times throughout the breeding season. A foraging survey protocol should be provided to the Service for review.

Targeted special-status wildlife sites are to be determined for each species by habitat evaluations based on vegetation mapping (Section 6.2.1). The Service requires sufficient information on the location of suitable habitats for special-status species and the presence of these species in order to analyze the direct and indirect effects of Project developments and operations, thus facilitating the development of effective PM&E measures.

Some of the wildlife studies proposed in the FSCP for the targeted special-status species are fairly general in description, such as for the California spotted owl, willow flycatcher, California thrasher, ring-tail cat, and several species of bats. Further descriptions of survey methods, along with the frequency and timing of surveys, should be made clear so the proposed study plans can be assessed prior to their inception. Additionally, the Pacific fisher should be added to this list.

6.4.5 Valley Elderberry Longhorn Beetle

At the May 3, 2002 meeting held at ENTRIX, Inc. with PG&E, it was agreed that elderberry (*Sambucus* spp) surveys would be conducted in conjunction with the special-status plant species surveys. It was also agreed that surveys would occur within 100 feet of project facilities and where maintenance activities occur, and 25 feet elsewhere, including the diverted reaches.

If you have any questions regarding our comments on threatened and endangered species please contact Kathy Brown at (916) 414-6600. For other general fish and wildlife issues, please contact Deborah Giglio at (916) 414-6600.

Sincerely,

David L. Harlow
Acting Field Supervisor

Enclosure

cc:
Service List

Literature Cited

Gore, J. A., J. B. Layzer and J. Mead. 2001. Macroinvertebrate instream flow studies after 20 years: a role in stream management and restoration. *Regul. Rivers: Res. Mgmt.* 17: 527-542.

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PROOF OF SERVICE

PACIFIC GAS AND ELECTRIC COMPANY

Project No. 606

KILARC-COW HYDROELECTRIC PROJECT

I hereby certify that I have this day served by regular mail, the foregoing letter, Subject: Kilarc-Cow Hydroelectric Project, FERC No. 606, Shasta County, California - Comments on the First Stage Consultation Package to each person designated on the official FERC Service list.

Dated at Sacramento Fish and Wildlife Office, Sacramento, CA this 30th of January, 2003.

Hee J Seto

Hee Ja Seto
Office Assistant

REGULATED RIVERS: RESEARCH & MANAGEMENT
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MACROINVERTEBRATE INSTREAM FLOW STUDIES AFTER 20 YEARS: A ROLE IN STREAM MANAGEMENT AND RESTORATION

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ABSTRACT

Over the past two decades of refinement and application of instream flow evaluations, we have examined the hydraulic habitat of aquatic macroinvertebrates in a variety of conditions, along with the role of these macroinvertebrates in sustaining ecosystem integrity. Instream flow analyses assume that predictable changes in channel flow characteristics can, in turn, be used to predict the change in the density or distribution of lotic species or, more appropriately, the availability of useable habitat for those species. Five major hydraulic conditions most affect the distribution and ecological success of lotic biota: suspended load, bedload movement, and water column effects, such as turbulence, velocity profile, and substratum interactions (near-bed hydraulics). The interactions of these hydraulic conditions upon the morphology and behavior of the individual organisms govern the distribution of aquatic biota. Historically, management decisions employing the Physical Habitat Simulation (PHABSIM) have focused upon prediction of available habitat for life stages of target fish species. Regulatory agencies have rarely included evaluation of benthos for flow reservations. Although 'taxonomic discomfort' may be cited for the reluctant use or creation of benthic criteria, we suggest that a basic misunderstanding of the links between benthic macroinvertebrate and the fish communities is still a problem. This is derived from the lack of a perceived 'value' that can be assigned to macroinvertebrate species. With the exception of endangered mussel species (for which PHABSIM analysis is probably inappropriate), this is understandable. However, it appears that there is a greater ability to predict macroinvertebrate distribution (that is, a *response* to the change in habitat quality or location) and diversity without complex population models. Also, habitat suitability criteria for water quality indicator taxa (Ephemeroptera, Plecoptera, and Trichoptera; the so-called 'EPTs') may also provide additional management options to stream regulators. The greatest application for macroinvertebrate criteria will be in low-order streams where a more immediate link to fish communities can be established. We present an example from Queens Creek, in North Carolina, USA, in which monthly allocations required to preserve the integrity of the benthic macroinvertebrate community were significantly higher than for the target benthic fish species, *Cottus bairdi*. In the months when both *Cottus* and community diversity of macroinvertebrates were the 'bottleneck' life stages, preservation of only fish species could result in an additional 5–25% loss in macroinvertebrate habitat. We suggest that, as there becomes an increased emphasis on maintaining macroinvertebrates as monitors of stream health, there will be a concurrent emphasis on incorporating hydraulic habitat conditions as a part of bioassessment. Copyright © 2001 John Wiley & Sons, Ltd.

KEY WORDS: IFIM; instream flow analysis; macroinvertebrate community diversity; mussels; PHABSIM

INTRODUCTION

Among the body of techniques used to evaluate minimum flows and to make flow recommendations for stream managers, the Instream Flow Incremental Methodology (IFIM) (Stalnaker *et al.*, 1995), along with the software associated with the technique (most notably, the Physical Habitat Simulation, PHABSIM) (Milhous *et al.*, 1984), has received the greatest attention from regulatory agencies around the world. In its original form, the ease of calibration of the one-dimensional flow model combined with relatively

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simple habitat characteristics of target fish has made its application appealing in a variety of water resource management conflicts. Being originally designed to address problems related to minimum or optimal flows for various life stages of salmonid species in rivers dominated by snowmelt hydrographs in the western United States, in general, other state agencies continued to apply the technique by addressing the flow requirements to maintain critical game species. Only recently has it been demonstrated that the single target-species approach is probably not appropriate to many river and stream ecosystems. For example, in the southeastern United States, warmwater rivers host among the most species-rich temperate freshwater fish assemblages in the world (Freeman, 1998). This high richness presents a number of challenges to choose appropriate targets for management and the development and evaluation of habitat-use guilds have often replaced the single-species approach (Freeman, 1998; Leonard and Orth, 1988). As an alternative, some regulatory agencies have chosen to evaluate several individual species, each being representative of specific habitat types. Quite often, a species of darter (*Etheostoma* or *Percina*, family Percidae) or sculpin [bullhead] (*Cottus*, family Cottidae) is evaluated to represent fast-riffle species. The assumption has been made that the maintenance of habitat for these riffle-feeders will certainly support the food base, those benthic macroinvertebrates species dwelling in the riffles. This assumption relieves regulatory agencies and system modelers of the task of creating habitat suitability criteria for a myriad of benthic species, not to mention the concurrent difficulties in collecting and identifying the various species dwelling in that lotic system. Over the past two decades of refinement and application of instream flow evaluations, we have examined the hydraulic habitat of aquatic macroinvertebrates in a variety of conditions, along with the role of these macroinvertebrates in sustaining ecosystem integrity. We suggest that evaluation of benthic fish species may not be an appropriate surrogate for aquatic macroinvertebrates. Macroinvertebrates are, effectively, food for fish. But, it remains very difficult to demonstrate that invertebrate density can influence fish growth and populations dynamics. Few studies (e.g. Mundie, 1974) have attempted to directly link macroinvertebrate and fish production. However, with the critical role of aquatic invertebrates in the processing of nutrients and organic energy in any running water ecosystem (see, for example, Cummins, 1996) and the increased emphasis on multiple-species conservation and management in all ecosystems (Pearson, 2000; Redak, 2000), it is becoming increasingly necessary to evaluate maintenance of macroinvertebrate communities in both regulated flow conflicts and in planning the restoration or preservation of critical habitat areas. Our examination of the appropriate use of macroinvertebrate habitat criteria in regulated stream management and restoration is the subject of this paper.

Although the instream flow requirements for benthic macroinvertebrates received equal attention during the development of IFIM, perceived difficulties in collection (large sample size), taxonomic identification, habitat suitability curve generation, as well as inability to assign 'benefit' to the maintenance of benthic communities have led most regulatory agencies to conclude that enough flow for target fish species (and their individual life stages) was also sufficient for benthic species, as a source of food. Even with increased emphasis on more comprehensive evaluation of lotic biota, there is a certain amount of controversy regarding the amount of effort required and/or the need for accuracy in the development of habitat models. When benthic macroinvertebrate evaluations are required, it is often left to the best judgement of the stream manager to decide the appropriate taxonomic level for management target. However, unless the target macroinvertebrate is listed as an endangered or threatened species under the Endangered Species Act of 1973, the larger question asked by the applicant to the regulatory agency is, 'Are aquatic macroinvertebrate studies necessary?'

NEAR-SUBSTRATE CONDITIONS

The interaction of depth and velocity with the substrate profile is of critical importance to the range of potential microhabitats available to benthic macroinvertebrates (Statzner *et al.*, 1988). When these simple characteristics are combined with such criteria as kinematic viscosity, density of the water, and power slope, such conditions as Froude number, shear velocity, thickness of the viscous sublayer and shear stress have been shown to be able to predict the distribution and, in some cases, the density of macroinvertebrates in a stream reach (Gore, 1996, provides a summary of these studies). Although studies of flow in flumes have indicated the existence of a non-moving boundary layer (up to 2 mm in thickness) (Nowell and Jumars, 1984) and lotic scientists have indicated that morphological and behavioral adaptations are directed towards existence within this boundary layer (Hynes, 1970), recent investigations have determined that very few benthic macroinvertebrates are sufficiently streamlined to take advantage of this boundary layer (Statzner, 1987). Indeed, a true boundary layer condition rarely exists under natural flow conditions because of the complex profile of the substrate. Thus, aquatic organisms are restricted to those combinations of velocity, depth, and substrate that allow morphological and/or behavioral resistance to flow to be exceeded by energetic gains.

Any hydrological change that leads to increases in shear velocities or shear stress or reduction in the thickness of the viscous sublayer will reduce the availability of adequate microhabitats to some species while increasing habitat availability for others. Since the abundance of various species will change with changes in physical habitat location and accessibility, in turn, community functioning and food-web dynamics may be changed to the extent that some species will be locally eliminated from the community.

Near-substratum conditions are further changed with changes in substrate composition or distribution since increased hydraulic roughness increases the rate of sediment deposition (Harvey and Watson, 1986), in turn, altering community composition through elimination of some species (increased predation success) (Brusven and Rose, 1981) or elimination of some or all primary production (Brusven and Prather, 1974).

THE 'VALUE' OF MACROINVERTEBRATES

Aquatic macroinvertebrates occupy a unique compartment within the structure of lotic ecosystem. As processors of organic material (either allochthonous or authochthonous), the invertebrates serve as the critical link to the fish community as food for game and forage fish. Gore (1977, 1978) showed that many macroinvertebrate species have a narrow range of tolerances to changes in discharge. Being less mobile than fish, most macroinvertebrates lack the ability to return to a previously inhabited area. Thus, under fluctuating flows, patches of slowly recolonizing habitat support a different community structure and very different densities of benthic species (Gore and Milner, 1990). IFIM predictions have demonstrated that a small-percentage loss of fish habitat may not necessarily result in a comparable loss of macroinvertebrate habitat, whose losses may be two- or three-fold greater (Gore, 1989). However, it is has been rare over the past two decades that macroinvertebrate habitat considerations have been made. This decline in the food base and/or community structure has the potential of leading to further degradation of the target fish species for management, as well as less efficient energy processing throughout the ecosystem. It is important, then, that prediction of changes in macroinvertebrate habitat be considered in conjunction with analysis of instream flow requirements for target fish species. This requires the assessment of the distribution of benthic species, construction of models of habitat suitability, and application of the models to appropriate hydrologic/habitat management models of that regulated stream or river. One of the most common assessment and management tools has been IFIM, and its associated software, PHABSIM (Stalnaker *et al.*, 1995; Bovee *et al.*, 1998).

MACROINVERTEBRATE HABITAT SUITABILITY CURVES

In addition to hydrological and hydraulic calibration data, PHABSIM requires information on the suitability of (or preference for) velocity, depth, and substrate criteria of target species for management. Although evaluation of macroinvertebrates is not common in the United States, previously published ('catalog') criteria have been used in limited application (see, for example, Bovee, 1985). However, on-site development of habitat suitability information yields the most accurate predictions (Bovee, 1986; Gore, 1987). This is especially important for benthic macroinvertebrates since community composition varies from system to system. Niche characteristics will change as a result of changes in predation, competitive interactions, habitat location, and availability, as well as food resources. Habitat criteria, as mimics of niche dimensions (Hutchinson, 1959), will likely change with changes in species composition or composition of functional groups in the community in any given lotic ecosystem.

Gore and Judy (1981) have developed a technique for describing macroinvertebrate suitability curves for PHABSIM application. This curve development relies upon standard techniques for benthic macroinvertebrate sampling. Using a circular bottom sampler (Waters and Knapp, 1961), Surber sampler (Surber, 1937), or other area-defining samplers, measurements of depth, mean water column velocity, and substrate characteristics are recorded for a series of samples (we suggest between 25 and 50 samples) taken at random along transects across a 'typical' stream reach. In most cases, riffle samples are used since these organisms are the most likely to be impacted by decreased flows (usually the management alternative being examined). Stratification of the sampling scheme, based upon proportions of substrate type, appears to reduce the number of samples required to produce accurate suitability curves (Statzner *et al.*, 1988).

Suitability curves are derived from a fit of a third- or fourth-order polynomial to a plot of cumulative mean number of individuals of a taxon per sample as a function of an arbitrarily chosen increment of each physical habitat parameter. As an alternative, cumulative mean sample diversity per habitat parameter can be plotted. Any of these plots results in a sigmoid curve-fit. The polynomial should be fit only over the range of physical habitat values measured.

A primary derivative of the fit polynomial (when normalized to a maximum value of 1.0; as greatest suitability) will provide a suitability curve applicable to the habitat simulation routines contained within PHABSIM. In the case of a plot of diversity values, this curve indicates habitat conditions that provide for maximum community diversity.

Since the initial polynomials are fit to plots of *mean* number of individuals per habitat increment, variance around each mean is implicit within the model. Orth and Maughan (1983) suggested log transformation of the raw data to minimize these variances prior to construction of the suitability curves. In some cases, log transformation has a tendency to skew the peak of the derived suitability curve toward the lower end of the physical parameter range.

RECENT APPLICATIONS OF PHABSIM FOR MACROINVERTEBRATES

In the United States, some regulatory agencies, most notably in the state of North Carolina, have begun to include macroinvertebrate habitat evaluations as a component of minimum flow evaluations. These evaluations have been made in recommendations for release schedules for hydropower facilities as part of re-licensing efforts with the Federal Energy Regulatory Commission and for allocating water abstraction rates for various municipalities. Most often, a suite of macroinvertebrate criteria has been used in the evaluations. No species-specific curves have been employed. Instead, more generic curves for the 'EPT fauna' [Ephemeroptera, Plecoptera, and Trichoptera] (Figures 1–3) have been evaluated, since many bioassessment metrics depend upon the richness of these orders when evaluating water quality (Barbour *et al.*, 1999). We have derived the EPT curves from a series of benthic samples (approximately 1200 individual samples with a minimum of 50 samples per location) taken over the past 10 years across a range of streams and rivers in the southeastern United States. In addition, representative criteria for benthic community diversity in high gradient or low gradient streams (the break point being arbitrarily chosen as a gradient of 0.005), as appropriate, have been concurrently evaluated. These curves have been derived from individual samples collated over the past two decades and represent some 2500 samples collected since 1974 in streams in the western, northeastern, and southeastern United States (Figures 4–6). The curves for velocity and depth were derived as the first-order differential of exponential polynomials fit to cumulative mean number of individuals (or mean sample diversity [measured as Shannon's diversity]) per increment of physical parameter, as described by Gore and Judy (1981). Substrate histograms were plotted as the mean number of individuals of that order (or mean sample diversity) per substrate category and normalized to one, as described by Bovee (1986).

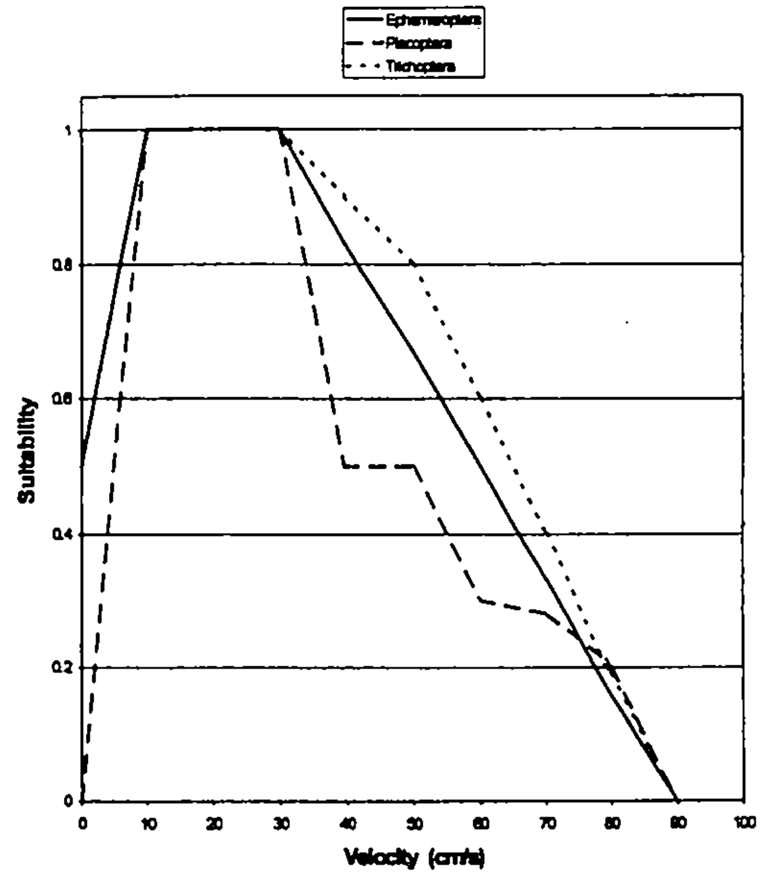

Figure 1. Velocity preference curves for EPT, based upon a pool of 1200 samples

Since we wanted to create a *generic* set of suitability curves, we chose to *simulate* a number of samples adequate to develop habitat suitability criteria. Statzner *et al.* (1988, 1998) have shown that, this value ranges between 25 and 75 samples. Thus, we chose to draw, at random, 50 samples from the pool of available samples. For each set of 50 samples, habitat suitability curves were created according to the methods of Gore and Judy (1981). This was repeated, as a Monte Carlo simulation, until the variance around the mean value for each increment of depth, velocity, and substrate remained stable. The *generic* curve was fit to the mean values for each increment of physical habitat condition. When this scheme was repeated more than 100 times, the curves were not significantly different from curves derived from all samples as a single pool. Thus, the curves presented (Figures 1–6) are, in effect, the mean preference curve based on all samples.

Figures 7 and 8 are from a series of evaluations of flow releases from Queens Creek in North Carolina. The recommended releases are based upon a time-series evaluation of 49 years of record, performed once with the mottled sculpin (*Cottus bairdi*), as a representative of the riffle fauna, and several other fish species and performed, again, with macroinvertebrate community diversity (high-gradient stream) and the same suite of fish species. With the exception of those times of the month when critical habitat conditions are required for the spawning of rainbow trout (*Oncorhynchus mykiss*), the true bottleneck is represented by adequate flows to maintain benthic diversity. That is, when using the mottled sculpin, alone, adequate habitat for macroinvertebrates is underestimated by between 5 and 15%. These results underscore the need to include macroinvertebrate community structure as a component of instream analysis in order to avoid the potential of providing inadequate habitat for secondary producers in the stream ecosystem.

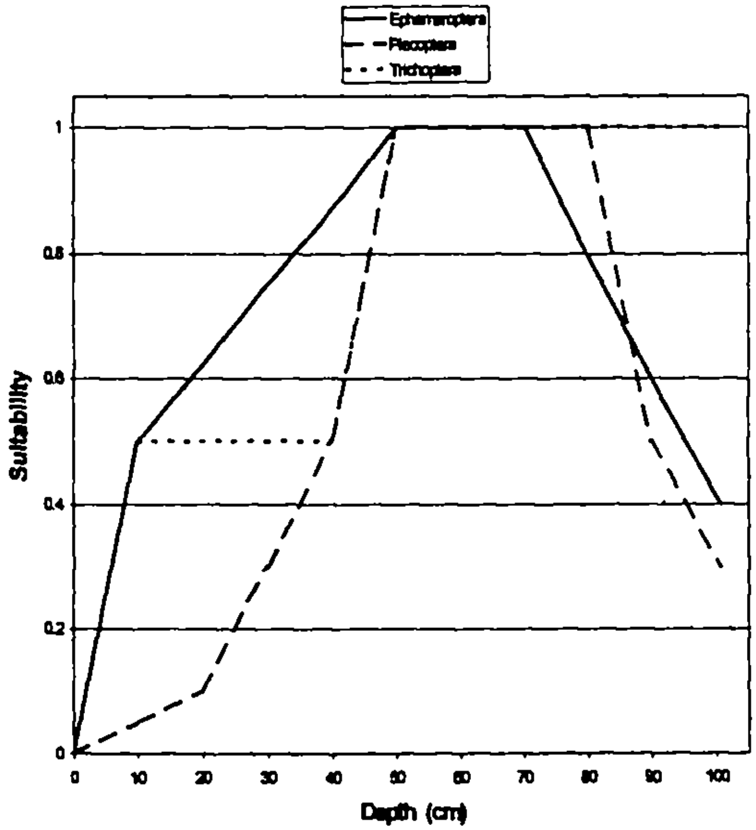

Figure 2. Depth preference curves for EPT, based upon a pool of 1200 samples

As discussed earlier in this paper, there are concerns about applying IFIM to assess the effect of flow modifications on southeastern streams of the United States, because of the high richness of fish species and limited knowledge of habitat requirements. Bowen *et al.* (1998) investigated the use of generalized habitat metrics, rather than species specific, as one potential approach to this dilemma. Parameters for five key habitat types were selected and IFIM site models were developed at seven locations along the Tallapoosa River in Alabama. Stream flow records for this river encompass both unregulated 'natural' flows and regulated flows following dam construction. Fish assemblage data for Cyprinidae, Centrarchidae, Catostomidae, and Percidae were also collected. Statistical analysis found correlations between the abundance of different fish groups and the median availability, as well as persistence, of each of the five habitat types. Adaptations of this approach are also planned for hydropower re-licensing studies at several locations in western North Carolina.

The use of generalized habitat criteria to augment species specific analysis is a promising development in the application of IFIM to stream management. It reduces the reliance on site and/or species specific habitat preferences that may include flawed assumptions. The analysis of persistence (in hours) and availability of key habitat conditions may also make this approach especially useful in evaluating the effects of rapidly fluctuating flows downstream of peaking hydroelectric projects. The application of the approach described by Bowen *et al.* (1998) could also be explored for its applicability to benthic macroinvertebrates. In fact, employing the low gradient or high gradient benthic community diversity suitability curves we have developed may approximate the use of generalized habitat metrics. Bowen *et al.* (1998) focused on spring and summer months as those critical for fish spawning. Benthos should be evaluated over the entire year because of their general lack of mobility, compared with fish.

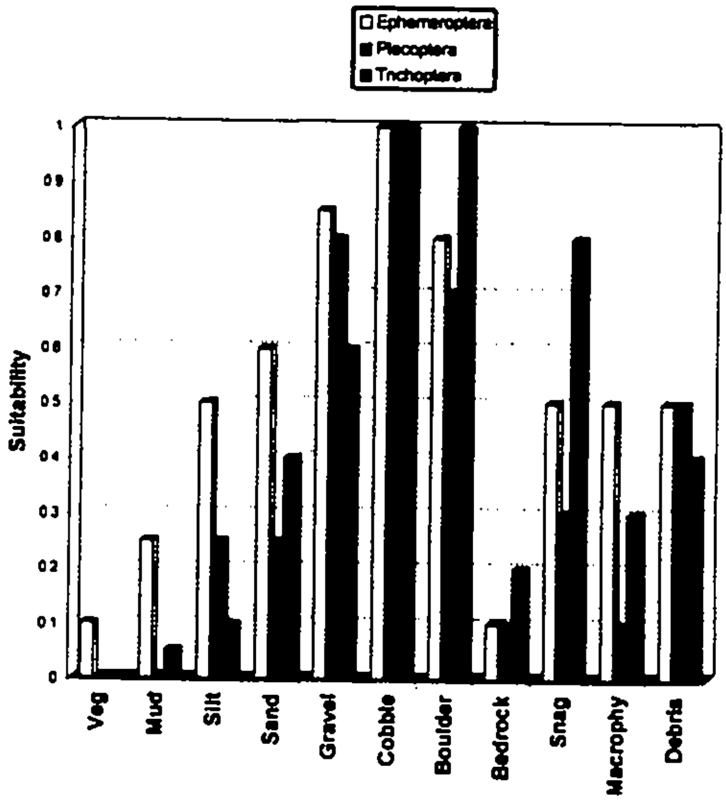

Figure 3. Substrate preferences for EPT, based a pool of 1200 samples

Another factor receiving increased attention in stream flow management is the potential for stream flow changes to alter substrate and channel morphology. A great deal of attention has been focused on minimum flows, but the elimination of occasional high flow events to flush accumulated sediment and maintain suitable substrate conditions can have long-term adverse consequences for habitat. This is especially true for benthic organisms. Richter *et al.* (1996) have developed a technique to assess this impact referred to as IHA—Indicators of Hydrologic Alteration.

The use of species specific IFIM analysis remains a useful and widely accepted approach to making stream flow management decisions. However, it can be greatly augmented by including benthic macroinvertebrate species, generalized habitat metrics, and indicators of hydrologic alteration to examine the full range of species, habitat conditions, and flow events. The application of generic curves does have advantages and limitations. The application of generic curves is certainly more cost-effective, especially when it is necessary to make a rapid decision on regulated river issues, and offers stream managers the chance to compare decisions and predictions across catchments and regions. However, these curves must be tempered with best professional judgement and, at times, altered (through a Delphi approach; Bovee, 1986) to fit known hydrological and physical conditions. When mussel species are involved, it cannot be demonstrated that the generic macroinvertebrate curves will adequately protect mussel species. Although Milhous (1991) has used HABEF, a subroutine in PHABSIM, to assess habitat availability for organisms with limited mobility, we suggest that the initial development of the suitability criteria remains problematic. Nevertheless, for most applications, where budgets limit the ability to gather field data and generate onsite curves, the generic curves appear to be the next best approximation of changes in habitat for benthos as a result of changing flow regimes. Since they represent a summary of preferences observed at many different sites, for comparative purposes, they may be more useful than site-specific criteria.

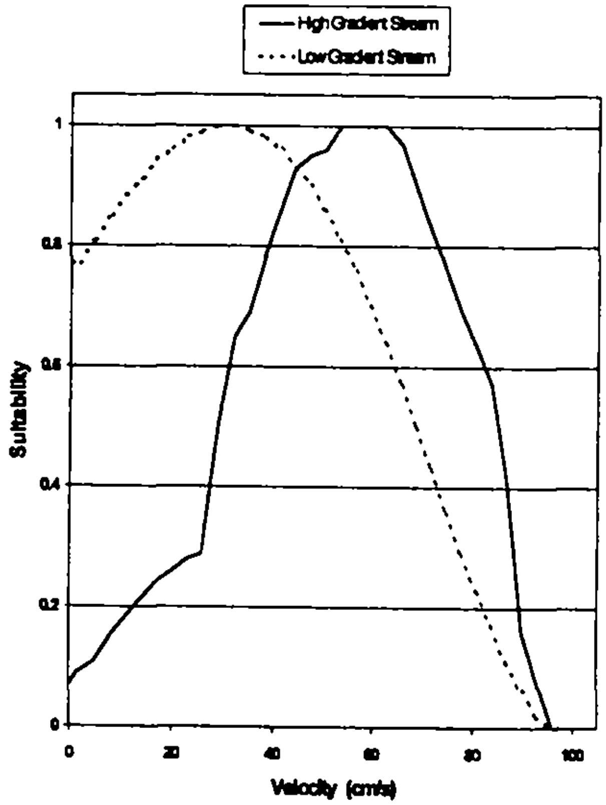

Figure 4. Velocity preferences for Macroinvertebrate Community Diversity in wadeable streams of different gradients, based upon a pool of 2500 samples

Although not a primary use of PHABSIM, the model is sufficiently robust to also allow application of the model in the evaluation of physical restoration of disturbed stream ecosystems. Gore (1985) suggested that such models might be used to evaluate the placement of structures in unregulated streams. More recently a number of attempts have been made to evaluate restoration efforts using PHABSIM. Subroutines within PHABSIM can be used to evaluate restoration design by changing cross-sectional information (channel geometry, substrate, velocities, etc.) to mimic proposed changes caused by placement of restoration structures. Wegner (1980) used this approach to evaluate the impact of excavation of pools, placement of weirs, and boulders on the Uinta River, but was unable to verify the results. Shuler and Nehring (1993) demonstrated that brown trout (*Salmo trutta*) habitat availability (as weighted usable area, WUA) and trout density were positively correlated over 3 years of study of restoration structures on the Rio Grande River. In these and other cases, the primary restoration effort has been focused upon recreating suitable target fish habitat.

The focus of within-channel restoration is the placement and construction of instream habitat structures to enhance the capture of organic detritus, promote the growth of periphyton or biofilm, as well as, improving the rate of colonization by macroinvertebrate and fish species (Gore, 1985). Structural design is based upon the assumption that these habitat requirements can be controlled through design of structures that produce preferred physical and chemical conditions as related to flow conditions. When emplacing structures that alter velocity, depth, and substrate composition, restoration scientists are assuming that hydraulic conditions are one of the primary templates that govern the distribution of lotic organisms (Brookes *et al.*, 1996). For benthic macroinvertebrates, substrate composition is the most easily manipulated habitat characteristic. The most common structures for fish habitat enhancement have been current deflectors, overpour structures (dams and weirs), bank cover, and boulder placements. These

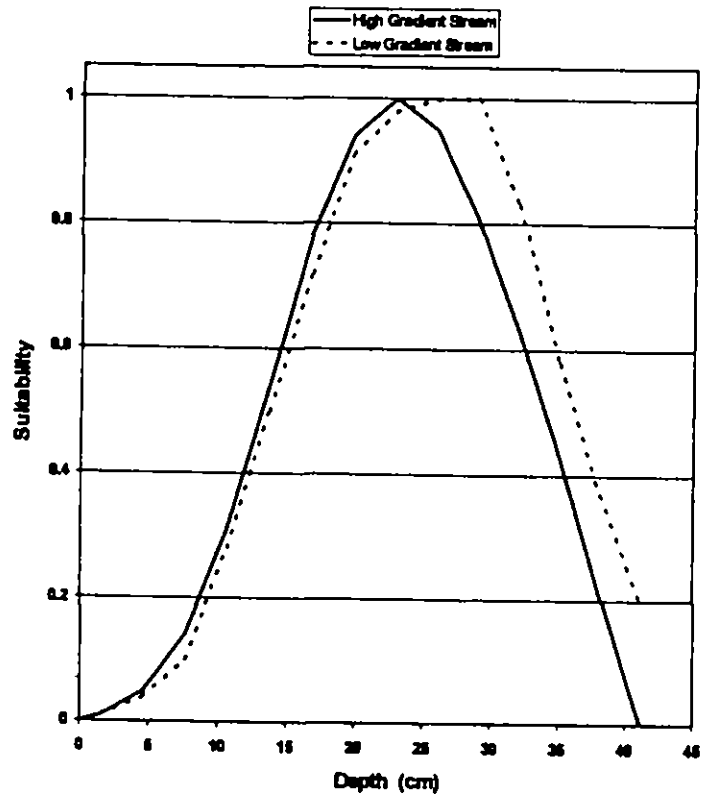

Figure 5. Depth preferences for Macroinvertebrate Community Diversity in wadeable streams of different gradients, based upon a pool of 2500 samples

instream structures also modify local hydraulic conditions to present preferred habitat to benthic invertebrates. PHABSIM has been used to evaluate stream enhancement activities with an emphasis on macroinvertebrate restoration. The placement of a series of three-log weirs on Brushy Branch, a second order stream in Tennessee, demonstrated that benthic macroinvertebrate habitat can be dramatically increased at low flows (up to five times higher) after placement of structures which improve hydraulic conditions to sustain maximum diversity of the benthic community (Gore and Hamilton, 1996). Just as in the case of predictions based upon numbers of individuals of a species, we assume that an increase in the quality of a habitat cell will result in an increase in diversity in that cell. It remains difficult to directly predict that response to increase in habitat quality. However, in a separate study, Gore *et al.* (1998) demonstrated that artificial riffles placed in Holly Fork, a tributary of the West Sandy River, in west Tennessee, enhanced macroinvertebrate diversity. That is, macroinvertebrate diversity increased with increases in habitat quality in each cell examined over a range of discharges. Indeed, PHABSIM was able to successfully predict the location of best habitat cells across the riffle at those discharges. The location of the optimal habitat changed from the head to the toe and back to the head of the riffle as discharge increased. Hydraulic habitat models, then, especially PHABSIM, can be a useful tool to evaluate the benefit of certain restoration activities. In low-order streams, evaluation of benthic communities may well be the best indicator of restoration success.

COMPLEX HYDRAULIC MODELS

Turbulence, shear stress, and other near-bed phenomena are the result of the simultaneous interaction of velocity, depth, and substrate. Thus, suitability criteria have been criticized for the lack of this

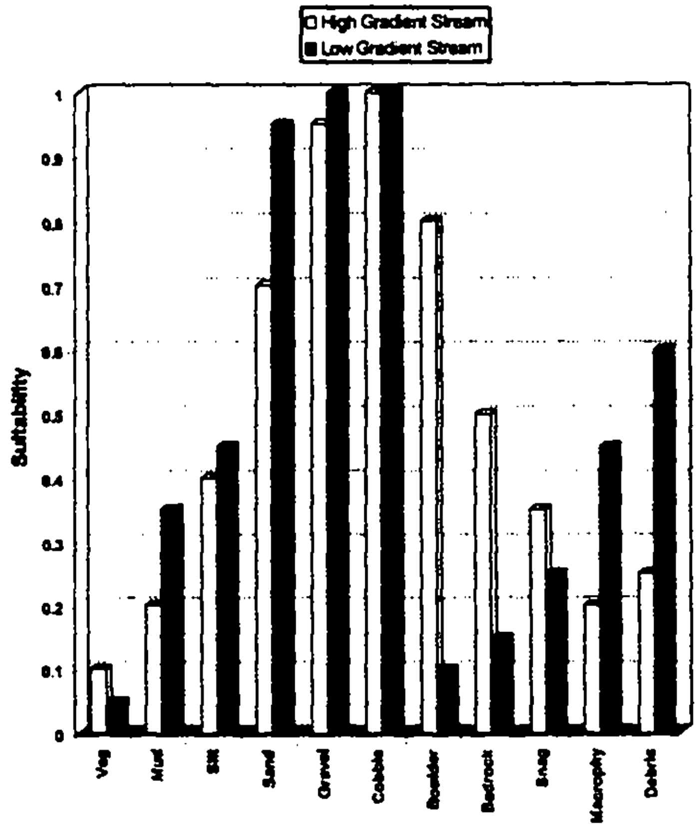

Figure 6. Substrate/Cover preferences for Macroinvertebrate Community Diversity in wadeable streams of different gradients, based upon a pool of 2500 samples

interrelationship in production of habitat information (Mathur *et al.*, 1985). Gore and Judy (1981) presented an alternate model that included joint velocity and depth terms in an exponential polynomial equation. A multiple regression of frequency distributions of velocity and depth provided the constants for the equation. The result is a *response surface* depicting the changes in preference as a function of changes in simultaneous change in depth and velocity. Morin *et al.* (1986) found that the exponential polynomial curves had the effect of minimizing variances and were more accurate density predictors than the standard IFIM suitability curves and their log-transformed modifications.

Statzner (1987, 1988) and Statzner and Holm (1982, 1989) have conducted extensive tests of the hydrodynamics of benthic macroinvertebrates and have produced a series of models of complex hydraulic conditions that accurately predict the distribution and density of aquatic macroinvertebrates. Although these models are, undoubtedly, more accurate, in ecological terms, the employment of these complex hydraulic models requires extensive modification of the habitat packages within PHABSIM to accommodate the suitability curves. HABTAT, for example, does contain options to examine shear stress and other near-bed phenomena, but remains based upon velocity, depth, and substrate curves produced independently.

At first, this may sound as a criticism of the currently employed habitat suitability curves and a call for the renewed development of macroinvertebrate habitat models. However, in a small number of tests of these models, PHABSIM appears to be doing a more than adequate job of prediction and as a management tool. Gore *et al.* (1998) found that composite suitability curves were able to predict community diversity of benthic macroinvertebrates in areas downstream of restoration structures on low-order streams. Similarly, Statzner *et al.* (1998), in a direct comparison of complex hydraulic models

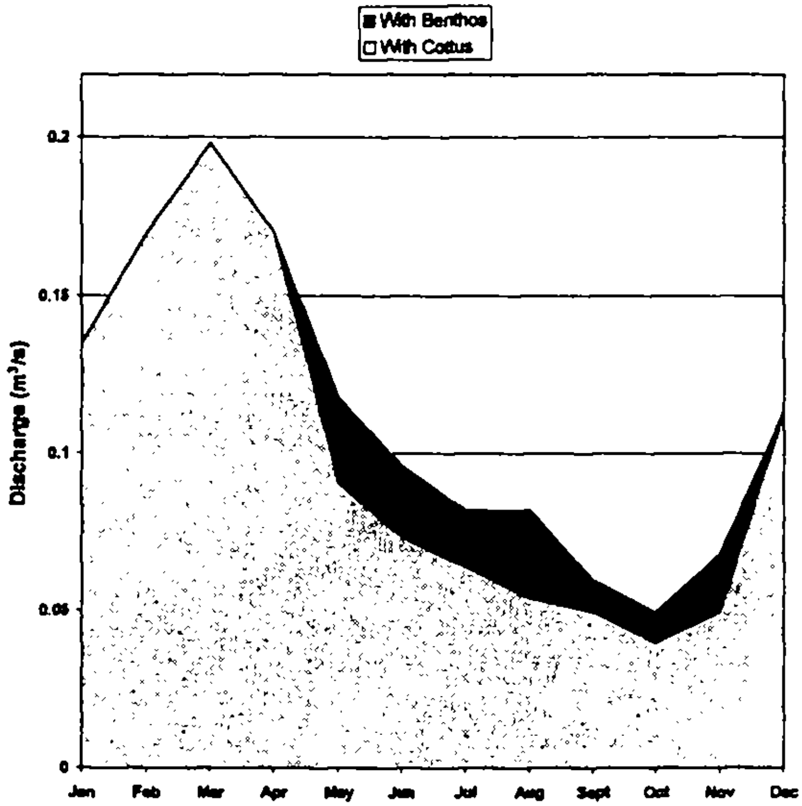

Figure 7. A comparison of recommended monthly minimum releases on Queens Creek, North Carolina, with a 20% reduction in habitat allowed. Based on predictions using only a riffle-feeding benthic fish (*Cottus bairdi*) and including benthic macroinvertebrate diversity. This results in a 4.3% annual volumetric increase to protect benthos

and the simpler habitat suitability curves used in IFIM, found that the simple habitat suitability curves did a better job of predicting densities, with smaller sample sizes required, when attempting to predict sample density of over 250 samples of *Aphelocheirus aestivalis* from rivers of central Germany.

MUSSEL FAUNA—NEW APPROACHES

Although many factors have contributed to the extinction of numerous freshwater mussel species and populations, and should be considered in mussel conservation (Layzer *et al.*, 1993; Chesney and Oliver, 1998; Killeen *et al.*, 1998; Hughes and Parmalee, 1999; Cosgrove *et al.*, 2000), we restrict our discussion here to the influence of hydraulics on mussel populations. Freshwater mussels differ from most other macroinvertebrates in several ways that can affect assessment of their instream flow requirements (Table I). In particular, the limited mobility of mussels mandates that a different approach be used to define their flow requirements. Layzer and Madison (1995) argued that suitability indices developed for one discharge were of little use in predicting mussel habitat at other discharges. Spatially, mussel habitats are often well defined and restricted to patches (mussel beds). Barring catastrophic floods that reshape the stream channel, the locations of these beds remain constant among years and over a wide range of discharge. Mussels cannot move quickly enough to follow the changing location of suitable habitat as discharge varies. Figure 9 is a hypothetical example of a PHABSIM prediction of suitable habitat based on typical habitat suitability indices developed at base flow (Q3). As flow decreases (Q2, Q1), there is decreasing overlap between the predicted location of suitable habitat and the actual location of the mussel bed. Superficial examination of weighted usable area would seemingly show little change in the amount of

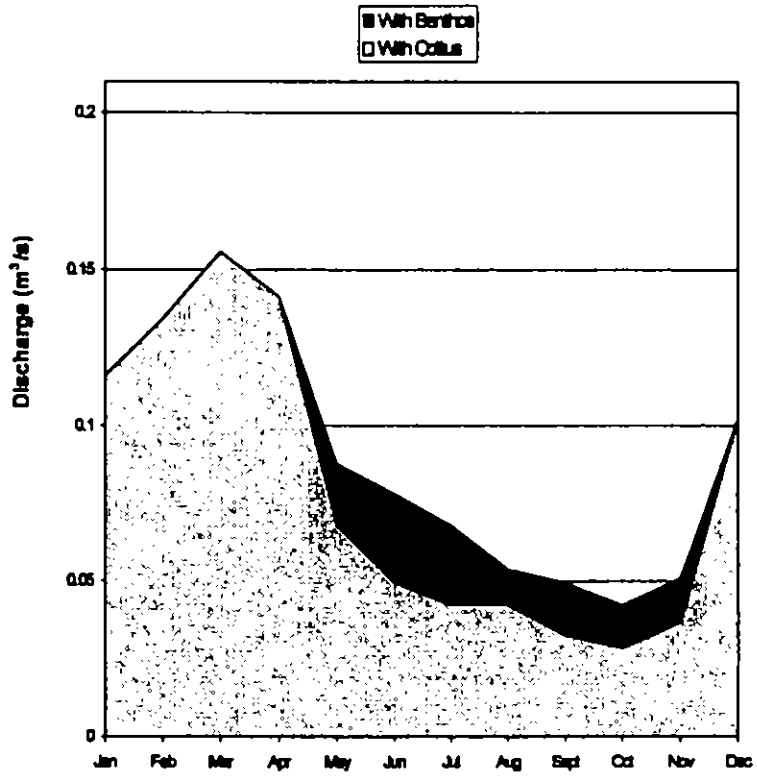

Figure 8. A comparison of recommended monthly minimum releases on Queens Creek, North Carolina, with a 35% reduction in habitat allowed. Based on predictions using only a riffle-feeding benthic fish (*Cottus bairdi*) and including benthic macroinvertebrate diversity. This results in a 13.9% annual volumetric increase to protect benthos

Table I. Characteristics of freshwater mussels and most other macroinvertebrates

Characteristic	Most mussels	Most macroinvertebrates
Life-span	Long (>30 years)	Short (<3 years)
Mobility	Limited	Moderate
Recruitment	Irregular	Regular
Recolonization	Slow	Rapid
Tolerance of adults to flow extremes	High	Low

habitat available as discharge decreased; however, because the mussel bed was not in the predicted area of suitable habitat, the decrease would be more severe than predicted.

Defining the physical environment mussels occupy in lotic systems has been the subject of much recent research (Holland-Bartels, 1990; Strayer and Ralley, 1993; Layzer and Madison, 1995; Hastie *et al.*, 2000). Despite these efforts, our understanding of preferred habitats and instream flow requirements of mussels is in its infancy. Layzer and Madison (1995) suggested that shear stress was a major factor in determining where juvenile mussels settled, and consequently, determines if recruitment to existing beds would occur. Strayer (1999) demonstrated that mussel beds were located in high-flow refugia. However, mussels are not uniformly distributed within a bed. Similarly, shear velocity varies on a small spatial scale within mussel beds and is negatively correlated with mussel density (Hardison and Layzer, 2001).

Although the use of a community model is suitable for determining flow requirements for most macroinvertebrates, such an approach is not appropriate for freshwater mussels. Available evidence indicates that instream flow needs are not necessarily the same for all species (Hardison and Layzer,

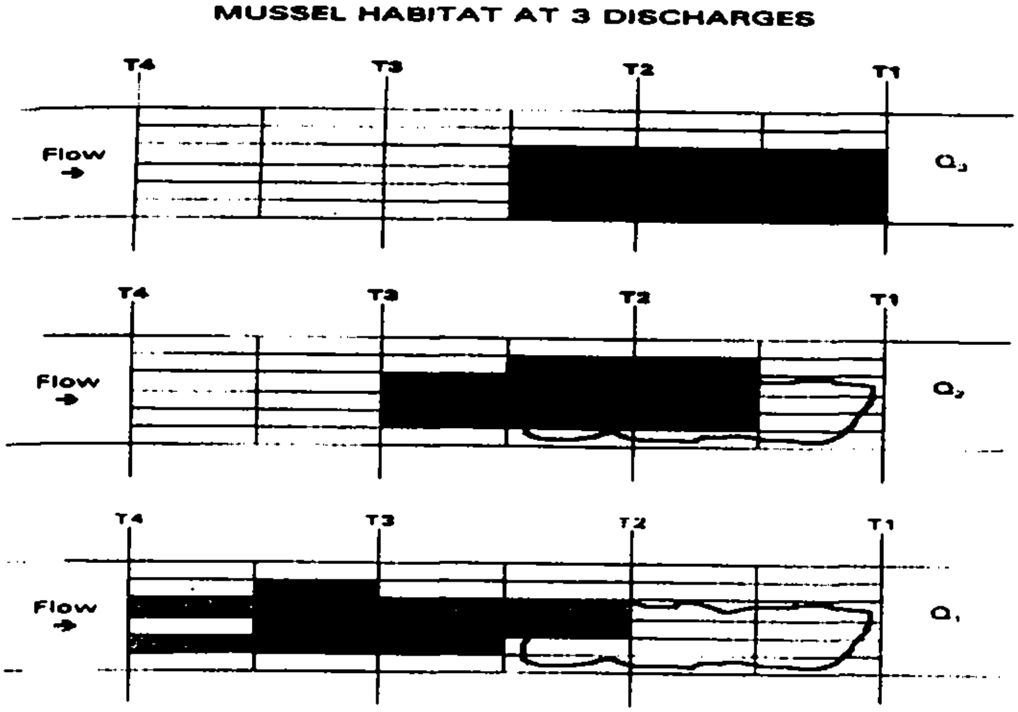

Figure 9. Hypothetical distribution of optimal habitat conditions (WUA) as discharge changes (Q1–Q3) across the stream reach; however, the mussel bed remains within the segment represented by transects 1 and 2 (T1, T2)

2001). Moreover, temporal variability in flows is believed to be important in maintaining diverse assemblages. Although the instream flow requirements for many macroinvertebrates has been the subject of research for over 20 years, specific attempts to delineate such needs for freshwater mussels is largely restricted to the past 5 years. Furthermore, actually providing a flow regime for mussel populations largely remains an untested management option. Layzer and Madison (1995) provided some interim recommendations for instream flow requirements of mussels, including minimum depths and velocities; however, they cautioned that these minima may be suitable only for temporary maintenance of mussel populations.

Many species of mussels live over 30 years, and in regulated and unregulated streams, successful recruitment is often highly variable among years. At least some of this variability is linked to variations in annual hydrographs. Recruitment for some species seems to be greatest at below average discharges, while other species may require a more normal flow rate for successful recruitment. Ultimately, recruitment is the sole measure of how successful any flow regime is for providing conservation flows for freshwater mussels. Therefore, we suggest a two-stage process for determining conservation flows for mussels. Initially, historic flow regimes should be linked to patterns in mussel recruitment. Following institution of a conservation flow regime, the level of recruitment should be monitored to insure that flows are suitable for maintaining or increasing existing population levels. To maintain diverse mussel assemblages, annual hydrographs may have to vary seasonally and annually to provide optimal flows for different groups of species. Although this recommended methodology does not lend itself readily to an IFIM analysis, PHABSIM should be used to assess habitat of host fishes, and flows necessary for instream movement. Moreover, PHABSIM predictions can be used to insure that suitable habitat for host fishes occurs in the immediate vicinity of mussel beds to increase the likelihood of successful glochidial attachment. We recognize that this proposed methodology will require much time and expense; however, it is justified to insure the survival of many mussel species on the brink of extinction.

CONCLUSION

Despite criticisms of PHABSIM and habitat suitability models for their lack of ecological sincerity, the IFIM technique provides a useful tool to stream managers to ascertain which flows will substantively alter habitat availability. The greatest need is the inclusion of macroinvertebrate suitability curves in the assessment of lotic ecosystem integrity under regulated flows. Differences in predicted optimal and minimum flow criteria do indicate that managing for a few target invertebrate species may result in the loss of habitat for other non-target species while flows that are appropriate for functional feeding group targets or for highest community diversity provide a greater proportion of habitat for benthic species. Maintaining a high community diversity among benthic macroinvertebrates or the appropriate proportion of functional feeding groups will likely insure a diversity of hydraulic conditions within the stream reach in question and it is a relatively simple procedure to produce suitability criteria for highest levels of benthic community diversity.

The second issue that faces the continued development of instream flow models applies to analysis of all trophic levels in stream ecosystems. That is, where should our efforts be focused in the future? Currently, we do not understand if or why more complex hydraulic models improve the predictive power of PHABSIM. The initial results of Statzner *et al.* (1988, 1998) are equivocal. Intuitively, it would appear that simulations of near-bed conditions *should* predict benthic macroinvertebrate 'responses' with greater accuracy and precision; however, this has not been the case. At the same time, parallel efforts are focusing upon more complex two- and three-dimensional models of hydraulic conditions (LeClerc *et al.*, 1995; Waddle, 1998) and more simple models combining multivariate and statistical models of habitat suitability (Lamouroux *et al.*, 1996). Should we focus upon improvement of biological models, hydrological models or both? Although we cannot suggest that any single approach is *best*, it must be the responsibility of the developers of new models to demonstrate that the application of the new models will significantly alter the management decisions that are being made using the more simple models being currently applied.

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