Proceedings of the Workshop on Instream Flow Habitat Criteria and Modeling

Edited by

George L. Smith

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WORKSHOP IN INSTREAM FLOW HABITAT CRITERIA AND MODELING

Edited by

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PREFACE

In 1975 the Instream Flow situation in the water administration arena was frustrating and confusing at best. While the water planning community was beginning to recognize that instream flow needs were a legitimate part of the water administration picture, investigation of instream flow requirements was a part-time job practiced by an uncoordinated group of biologists using a variety of methods.

Instream flow assessments had traditionally arrived at a single stream flow value - a "minimum flow." Such recommendations were usually determined solely from analysis of hydrologic records, and because of inherent threshold connotations provided only limited opportunity for negotiation and compromise.

The critical need for a coordinated, substantive effort to provide a focus for the multitude of divergent efforts ongoing in instream flow activities was documented in a 1975 statement by the U.S. Fish and Wildlife Service, Division of Ecological Services, in a document entitled "Toward a National Program of Substantive Instream Flow Studies and a Legal Strategy for Implementing the Recommendations of such Studies." A review of the literature (Stalnaker and Arnette 1976) indicated that neither adequate quantitative techniques nor sufficient data were readily available to solve the types of complex problems being encountered by the U.S. Fish and Wildlife Service field offices and the various state fishery management agencies.

Thus, in July 1976 the Cooperative Instream Flow Service Group (IFG) was established as a multi-agency, interdisciplinary entity to serve as a center of activity and provide direction for instream flow assessments. The objectives of the Group were threefold: 1) identification of instream requirements through accelerated application of improved methodologies; 2) development of guidelines for attaining implementation of instream flow recommendations; and 3) establishment of an effective communication network pertaining to instream flow activities, data and information. With this charge, the IFG undertook development of a comprehensive state-of-the-art methodology for identification of instream requirements (objective 1) in three steps:

1. Synthesize and transfer to the field of practical quantitative techniques based on state-of-the-art information for immediate application to current problems.

2. Promote and direct future research and development of quantitative techniques and data collection efforts to maximize their usefulness to the fishery management and water administration agencies.

3. Continually update and improve operational techniques as new technology is shown to be practical.

By fall of 1977 the IFG had drawn upon experiences of western fishery biologists and water planners to synthesize a unique state-of-the-art approach to instream flow assessments. The IFG's Incremental Methodology attempts to provide for the quantification of the amount of potential habitat available for a species by life history stage as a function of stream flow.

Initial application of IFG's methodology to selected western instream flow questions proved to be very promising. These early successes resulted in a notable demand for wide scale application, and stimulated considerable interest in the use of this new tool to address a variety of questions pertaining to impacts of changes in flow regime or stream channel geometry on instream fishery resources.

In November 1978 it was both timely and appropriate that the IFG's methodology be reviewed by user groups and the scientific community to obtain their assessment of this new tool's ability to do the job it was originally designed to do, and to do those new jobs that many were rapidly coming to expect it to do. Hence, a group of nationally recognized scientists and practitioners were invited to an Instream Flow Criteria and Modeling Workshop conducted by the Colorado Water Resources Center on the Colorado State University campus.

The express purposes of the workshop were to 1) provide the IFG with a critique of the existing components of their methodology on both conceptual and procedural levels; and 2) to assist the IFG in identifying needed refinement and prioritizing future development. A summary of the workshop discussion and subsequent recommendations pertaining to present day application and future research are reported in these Proceedings in reference to four broad topic areas: River Mechanics and Watershed Processes, Water Quality, Fishery Ecosystems and Instream Recreation.

KEYNOTE ADDRESS

Leo M. Eisel
Director
U. S. Water Resources Council

I am pleased to have this opportunity to speak to you this evening on the very important topic of maintaining adequate instream flows. I am also pleased that the Water Resources Council has had an opportunity over the past few years to contribute to further work and assistance in the production of methodology for determining necessary minimum instream flow requirements.

Over the past few years, the Water Resources Council, under authorities contained in Section 13 (a) of the Federal Nonnuclear Act of 1974, has made funds available to the Fish and Widlife Service and the Cooperative Instream Flow Service group for various phases of the work. In the course of preparing this speech, I have had the opportunity to review several of the documents produced by this program and am quite pleased with the results. The money has been well spent.

I am sure that many of you here tonight have a great deal more experience and insight into the problems of maintaining adequate minimum stream flows than I do. I am also sure that many of you have spent a great deal more time working on this problem and are very familiar with the various technical, legal and political problems involved. Nevertheless, I would like to ask all of you to take a step back from the many details involved in your efforts and to view the problem of maintaining adequate minimum stream flows from the larger perspective of water resources management.

There is no doubt that maintaining minimum flows will be one of the major water problems over the next few years and that this problem will probably continue to get worse before it gets better.

For example, the Water Resources Council's Second National Assessment of the Nation's Water Resources, which is scheduled to go to the printer the first of next month, has attempted to make some rather crude estimates of instream flow requirements for the major river basins and sub-basins in the United States. In the course of this analysis, it was assumed that 60 percent of the average annual flow of a stream would provide a base flow which in turn would provide excellent to outstanding habitat for most aquatic life forms during their primary periods of growth and for the majority of recreation uses. It was further assumed that 30 percent of average annual flow would provide good survival habitat for most aquatic life forms. Finally, it was assumed that 10 percent of average flow could sustain only short term survival habitat for most aquatic life forms. This somewhat crude and general analysis indicates that nationally, ideal flow levels for preserving instream uses would total about 1,040 billion gallons per day. With an average daily flow of 1,242 billion gallons per day in 1975 for all river basins in the United States, it appears that flows are adequate at present for fish and wildlife. However, several regions do not reflect such favorable conditions. For example, the Lower Colorado River has an average daily flow of about 1,550 million gallons per day, while the flow for ideal fish habitat should be almost 6,900 million gallons per day. Needless to say, these national and regional estimates are not very useful for purposes of planning water resources development and the preservation of minimum streamflows for specific streams. However, they do provide some indication of the national picture.

Data from the Second National Assessment as well as other analysis leads to the general conclusion that conflict over minimum flows is only going to get worse. The United States currently has no policy on population or economic growth and because our economic growth continues at approximately 4 percent per annum and our population growth continues at something like 1 percent, it is apparent that there will be increased competition for water and for remaining streamflows throughout the United States.

Another major problem which will continue to produce conflicts over minimum flows is the lack of an adequate water resources planning system within the United States. A great deal of effort has been made at the Federal level, as well as State and local levels, to do regional, water resources planning. The Water Resources Council itself was set up by the 1965 Water Resources Planning Act along with the river basin commissions for purposes of improving water resources planning. However, these and other institutions have not yet succeeded in providing the necessary adequate planning system required for preserving minimum instream flows. Here, we can draw on an example very close to Ft. Collins -- the Platte River. Perhaps the Platte River provides an almost stereotypic example of the shortcoming of our existing planning process. I would imagine most of you are familiar with the Narrows Reservoir and the controversy surrounding this project. Without going into the various figures concerning this project, it will result in depletion of flows downstream on the Platte River with possible impact on critical wildlife habitat for whooping and Sandhill cranes. A similar project, the Grayrocks Reservoir in Wyoming, will also impact on this same area of wildlife habitat. Unlike the Narrows Reservoir in Colorado, which would be built by the Bureau of Reclamation, the Grayrocks Dam and Reservoir is being constructed by a private entity using loans guaranteed by the REA. Unlike the Narrows Reservoir project, the Grayrocks Reservoir is not subject to the Principles and Standards of other Federal water resources planning requirements. As a consequence, the impact of this reservoir on a wildlife habitat and flows in the North Platte and main stem of the Platte River are not really considered in the context of the entire water resources of the Platte River Basin.

Shortcomings in State water law will also continue to insure inadequate consideration of low flows in many States.

There have also been recent setbacks in Federal legal decisions. For example, a recent Supreme Court decision concerning the Rio Membres essentially indicates that streamflows cannot be preserved for any other purpose on U.S. Forest Service land beyond the original purposes for which the land was set aside -- in this case, growing trees.

The point here is that within the near future these many factors -- that is, continued growth, poor planning, inadequate State and Federal law -- will produce continued pressure on the preservation of adequate minimum streamflows.

Probably to most of you here in this room it is obvious that the preservation of minimum streamflows depends on a lot of things. The first is an adequate system for quantifying the necessary flows. In addition, there also has to be an adequate planning system and an adequate decisionmaking system to insure consideration of the required minimum flows.

The first and most basic step in insuring preservation of minimum streamflows is undoubtedly to put together a procedure which can be used to quantify the relationship between flow characteristics and the habitat for a number of species as well as recreational use. This procedure must not have exceedingly complex computational requirements nor must it demand data which can be gathered only at great cost and effort. In short, the procedure needs to be as simple and cheap as possible while still providing information of necessary quality.

Needless to say, this is a big order as many of you here in this room know. I might draw an analogy between the task you are involved in and the similar task of mapping floodplains for purposes of floodplain management. As many of you know, a floodplain management program generally requires the aerial extent of the area inundated by the 100 year flood to be estimated since in most cases actual stage readings for the 100 year flood will at best be available at only a few locations on a stream. During my experience in the State of Illinois as head of the State water resources agency, I had a great deal of experience with floodplain management and quickly learned the need for solid and dependable floodplain mapping. I believe that a similar requirement exists here for solid and dependable information concerning the relation between various streamflow conditions for a specific stream and the suitability of wildlife habitat.

Because this is a workshop on instream flow criteria and modeling, most of you here tonight are primarily concerned about quantifying the relationship between streamflows and wildlife habitat. However, someone must also worry about the rest of the requirements necessary to insure that adequate minimum flows will be preserved. Here we are talking about improving systems for water resources planning as well as changes in State and Federal laws.

Taking the last of these first -- the State water laws -- I think that this is clearly a State problem in which the Federal government should not intervene. Last year in the course of the water resources policy review, the President, as well as Secretary of the Interior Andrus and Vice President

Mondale, made it very clear during several trips to the West that the Federal government would not interfere with State water law.

I do not want to take time tonight to review the various deficiencies in State water law where they occur, but the point is that if these State water laws are to adequately recognize instream flows, the States must take responsibility for change.

I'd like to spend a little time talking about efforts at the Federal level to insure that a more realistic planning procedure is in place which can accommodate the procedures which you are developing for purposes of considering instream flows. Without a solid water resources planning system, the procedures that this workshop is concerned with -- will simply not be used.

As I indicated earlier, existing water resources planning procedures at the Federal level are not adequate and many problems exist. For example, the Principles and Standards for the planning of water and related land resources development do not cover a number of Federal actions. Per direction of the Water Resources Council, the Principles and Standards really only cover direct Federal actions; that is, the construction programs of the Corps of Engineers, the Soil Conservation Service, the Bureau of Reclamation and TVA and do not cover the so-called "indirect Federal programs" such as the grants program of U.S. EPA for construction of sewage treatment facilities.

Another deficiency is the fact that the plans produced by river basin commissions, interagency coordinating committees, and other entities can be presently ignored by the Federal agencies and States without any kind of penalty. Another area of deficiency in the existing planning process is the almost complete lack of integration of water quality and water quantity planning in the United States. Here I can again draw upon my experience in the State of Illinois where the Federal government will spend approximately $17 million for purposes of 208 planning by next spring. All of this 208 planning is generally based on the 7 day/10 year minimum low flow. However, because water resources development planning is generally excluded from 208 planning, and likewise there is little effort to integrate 208 planning into water resources development planning, there really is no guarantee that the 7 day/10 year low flows will be there in the future with that frequency.

Okay, so much for the problems; now what efforts are being made at the Federal level to solve some of these problems with our existing water resources planning system. Most of these efforts are entered in the implementation of the water policy review directives which the President issued last July 12. Maybe I should just take a moment here to give you a capsule description of the water policy review for those of you who have not been following this effort closely. In May of 1977, the President directed OMB, the Council on Environmental Quality and the Water Resources Council to complete a review of existing Federal water policy and make recommendations for change. This review was initially to be conducted in 90 days but stretched on until last July when the President issued directives to a number of Federal agencies including the Water Resources Council for implementation of various policy changes.

I'd like to take this opportunity to summarize some of these directives and point out how I believe they can make a major contribution to insuring the use of the procedures for estimating low flows that you are concerned about developing.

One of the directives which the President issued went to the Water Resources Council and directed the Council to modify the Principles and Standards as well as produce a manual for use by the various Federal agencies for purposes of improving the implementation of the Principles and Standards. As many of you here know, the Principles and Standards for Planning Water and Related Land Resources Projects were originally issued in 1973. As their name implies, the Principles and Standards are a set of general principles and standards concerned with water resources planning, including benefit-cost analysis. The various Federal agencies, such as the Corps of Soil Conservation Service, develop their own agency rules and regulations for implementation of the Principles and Standards. As a result, there is considerable difference between the benefit-cost procedures and other planning procedures used by the Corps of Engineers, the Soil Conservation Service, and other Federal development agencies. As a consequence, the President has directed the Council to prepare a manual to insure more consistency among agencies in benefit-cost analysis and other planning procedures as well as insuring that the procedures used by the agencies are the best possible. I think the importance of all of this to you is that by improving planning and planning procedures, you have more of a guarantee that the procedures you are presently developing for estimating minimum streamflows will actually be employed and will not be just left on the shelf someplace.

The initial efforts of the Water Resources Council toward meeting the President's directive have been primarily concentrated in improving procedures for benefit-cost analysis. Our present schedule calls for us to have completed the portion of the manual dealing with benefit-cost analysis by next July. However, the Principles and Standards are not only concerned with economic cost and benefits. The P&S also requires an environmental quality plan to be developed and the procedures used by the agencies for this purpose vary even more and are less sound that those used for traditional benefit-cost analysis. As a consequence, we plan a second phase to improve the procedures used by the agencies for developing the environmental quality account. Procedures for instream flow criteria will be important for the traditional benefit-cost analyis portion of the manual but will be crucial for the environmental quality portion. Consequently, as we move into this second phase after the first of the year, we will be in close contact with you concerning the procedures you are developing. You may ask why the environmental quality account procedures have been reserved for the second phase. Why is it not important enough to be in the first phase?

The basic excuse is the age-old one used by bureaucrats of not enough time and people. The Presidential directive ordered us to have this manual completed by next July, which requires us to have a draft completed by about February 1 of next year in order to provide adequate time for publication in the Federal Register, a 90-day review period, and then development of the final document. We felt that there was no way we could really adequately develop definite procedures for the various areas of the environmental quality account in such a short period of time.

Closely aligned with the P&S manual directive is another directive to the Water Resources Council to develop an independent review function. Simply stated, the purpose of this review is one of quality control. The Water Resources Council will establish a technical group to assure that agency project plans are done in compliance with the Principles and Standards, the Fish and Wildlife Coordination Act, and other Federal laws and regulations. The general objective here is not for the water Resources

Council to vote a project up or down, but rather to insure that everyone is playing the game by the same rules.

I think that the independent review function will also insure better planning procedures and more serious consideration of procedures such as you are developing here for purposes of estimating required minimum streamflows.

There are a number of directives concerned with water conservation. I don't want to go into each of these individually, but merely give you some flavor of what these directives are all about. I believe that the decision by President Carter to make water conservation a cornerstone of Federal water policy is definitely a step forward as far as insuring adequate minimum streamflows for purposes of wildlife habitat and other uses. Because of the increasing future demands for water resulting from increasing economic and population growth, any successful efforts at reducing overall demand is bound to reduce the pressure on required minimum streamflows. For example, one of these directives requires all Federal agencies to review their existing programs by October 30 of this year and to report to the Water Resources Council ways that existing programs can be changed to promote water conservation. We are just now beginning to receive the first reports. Other areas involve things like cost sharing. The President has directed that legislation be drafted by the Water Resources Council to require 5 and 10 percent cost sharing by States for water resources projects. The purpose of this cost sharing is to insure more critical review of the need for water resources projects by States, thereby helping to insure that unnecessary water development projects will not be built.

Other directives have also concerned cost sharing. For example, the Bureau of Reclamation received various directives to promote more adequate pricing of irrigation water with the eventual goal being less wastage of irrigation water. The President also directed the Water Resources Council to establish a water conservation technical assistance grants program of $25 million annually. These funds would go directly to the States for purposes of assisting them in water conservation. Other directives concerned the Departments of Interior, HUD and Agriculture, for water conservation efforts in water short areas as well as water conservation in agricultural assistance programs in water short areas. EPA has been directed to essentially attach water conservation conditions to their loan and grants programs.

I could go on and give a few more examples here but the point is that a major portion of the President's water policy reform has centered on ways to reduce demand for future water development. In the past, major emphasis on Federal water programs has been on increasing supply. In contrast, President Carter has indicated the need for new emphasis on reducing demand.

Several other areas of reform directed by the President in his July 12 set of directives include increasing an existing State planning grants program at the Water Resources Council from approximately $5 million to $25 million annually. The purpose of this program is to improve State water resources planning. Again, we can always be critical of planning, but if the planning process is not adequate, the type of procedures that you are concerned about developing here today may not be integrated into decision-making process for purposes of water resources development and management. The President also directed more strict enforcement of existing laws such as the Fish and Wildlife Coordination Act. As many of you know here, enforcement of the Fish and Wildlife Coordination Act has been somewaht lax in the past. It has not been applied uniformly to water resources development.

There were also some directives which concerned instream flows directly. I am personally somewhat concerned that these directives are weak and could have been stronger; however, we were faced with the problem of essentially what can the Federal government do in the area of instream flows without becoming entangled in State water law.

Now obviously the question is: How much good are all these directives going to do? How much water are the water conservation directives going to save? Will planning be improved sufficiently to really consider the kind of procedures you were developing here? I am afraid that I cannot adequately answer any of these questions. We've simply got to wait and see.

I think that the point of all of this once again is that the work you are doing here is very vital and is absolutely necessary if procedures and requirements are put into place for insuring future minimum streamflows. It's just the same as floodplain management. You must first have the maps. However, these efforts of quantification of required minimum streamflows are only one part of a very complicated process. Without adequate planning and decisionmaking processes, your procedures for estimating instream flow needs will be ignored. Consequently, I have tried to put your work here in the big picture and demonstrate its importance as well as the importance of other components of the system.

Thank you for this opportunity to comment.

EXECUTIVE SUMMARY

The Cooperative Instream Flow Service Group, U. S. Fish and Wildlife Service, Fort Collins, Colorado has developed an incremental methodology which is unique among instream flow habitat assessment procedures. The Instream Flow Group Incremental Methodology (IFGIM) allows quantification of potential habitat available to various life history phases of a fish in a given reach of stream, at different streamflow regimes with different channel configurations and slopes. It is an emerging technology made necessary by increased public desire for concious consideration of acceptable habitat for instream biota. Modifications are constantly being made to improve its utility and this workshop was designed to accelerate that process.

Discussions were held involving experts in four specific areas relevant to the basic concepts of the IFG Incremental Methodology. Those areas were: (1) river mechanics, morphology, and watershed processes; (2) modeling instream water quality; (3) instream fishery ecosystems; and (4) relationships between recreation and instream flow. Workshop objectives were: (1) identification of avenues for improvement or expansion of the incremental methodology; and (2) identification and establishment of priorities for needed research and development programs for improvement of the incremental methodology.

The workshop on river mechanics, morphology, and watershed processes focused on: (1) an evaluation of current, predictive methodologies involving mathematical models - regression, lumped parameter, or physical process simulation - and using three mathematical approaches - analytical, finite difference and finite element; (2) an evaluation of the hydraulic components of the IFGIM that are utilized for determining management aspects of instream flow needs; (3) identification of possible improvements to the IFGIM's existing hydraulic simulation models; and (4) making recommendations pertaining to the addition of sedimentation aspects of instream flow into the methodology.

Five specific improvements were identified as necessary for increasing the predictive capability of IFGIM: (1) an improved approach to predictin watershed response due to duration, quality, and frequency of flow including consideration of the impacts of forest harvesting, irrigated agriculture, grazing, mining, and other watershed management activities on the water and sediment yield from watersheds to stream channel; (2) increased capability of the spatial resolution of the IFG models to accomodate both upstream management plans of small watersheds and legal requirements for instream flow needs, environmental quality, and water resource management for a complete river basin or subbasin; (3) the models should not be area or regionally specific; therefore, the models will require site-specific calibration data and regionally specific species response criteria; (4) the model should be able to explicitly represent management activities and simulate the system response resulting from these activities; and (5) increased capability to assign probabilities to climatic and spatial variables.

In addition to the foregoing improvements the following characteristics are desired in predictive models: (1) they should be functional within the constraints of limited data; (2) they should be oriented for use by management personnel and applicable to specific decision-making processes; (3) they should possess the capability of making predictions at different levels of accuracy and resolution depending on purpose of the assessment; (4) the computer software system should adopt a modular approach; and (5) the models should be properly documented.

A hierarchical analytical approach was proposed for IFGIM toward quantification of watershed processes and sedimentation as integral components of the riverine ecosystem. The workshop set forth the sequential levels of analysis required to develop and conduct an integral analysis of watershed processes and sedimentation. A given level of analysis is to be formulated, verified and utilized depending on level of accuracy required; available data; constraints; magnitude of projected channel changes; etc.

The module for instream water quality, recommended that incremental development be undertaken that would introduce water quality aspects to instream flow needs assessments. To be useful, such development must be applicable to the following problems: (1) the redistribution of water over a year (or periods of years) to increase low flows and/or reduce flood flows; and (2) the installation of major diversions up stream which decrease available flows. The context of these problems could be: (1) the need to establish instream flows as a part of a long range planning process; (2) the need to make operatinal decisions on f real-time basis to maintain minimum low flows; and (3) the evaluation of Environmental Impact Statements of projects that would change instream flows. No limit is specified for the site of a river system.

This group stressed the introduction of water quality methodologies must be an evolutionary process that will improve as the IFG staff develops in-house skills in water quality analyses. The workshop also proposed that the methodologies be classified according to their cost, required knowledge, data needs, and ability to resolve a basic low flow/water quality issues. Four classes were identified: (1) level one - will be to provide low cost, crude estimates of potential water quality problems. Text book concepts and heuristic approaches will be used; (2) level two - will estimate changes in temperature and oxygen due to flow alterations within a factor of two. This level requires limited field studies and textbook level analysis of the fate of pollutants such as heat, oxygen demand, solids, etc; (3) level three will expand the set of chemicals to be analyzed and attempt to employ state-of-the-art technology. This level requires extensive field observations and mathematical modeling to predict time-dependent fluctuation in heat and chemical concentrations in a reach; (4) level four involves research and development concepts that attempt to improve the current state of knowledge of the fate of toxic pollutants and to define chronic exposure levels that impact the aquatic ecosystem. This level will seek to add to scientific understanding as the first priority, and will complicate rather than clarify most management decisions.

This module's report concludes with examples of methodologies for each proposed level of analysis.

The workshop on instream fishery ecosystems concentrated on a critique of the incremental methodology as it pertains to fish, both as a concept and as an analytical approach.

Two major criticisms were made: (1) the methodology is not a consistent system of strongly interacting components, but a collection of specific modules interrelated by stream hydraulics; and (2) the methodology is based on a narrow set of physical parameters providing necessary, but not sufficient, conditions for the suitability of stream habitats.

The workshop proposed the development of an ecosystem holistic viewpoint by IFG to overcome the two major criticisms. The methodology now used should be expanded to include parameters that reflect chemical and biological processes of ecosystems. Recommended parameters, in order of importance, are: (a) depth; (b) velocity; (c) temperature; (d) food supply; (e) riparian cover, and (f) competition. Additional factors of less importance (unranked) include: (g) predation; (h) substrate; (i) dissolved oxygen; (j) instream cover; (k) nutrients; (l) stream morphology; and (m) sediment load.

The following avenues for improvement or expansion of the incremental methodology were identified: (1) an alternative to weighted usable area should be sought for use in simulation of stream flow phenomena; (2) the choice of modules in the hierarchical modular approach should be reevaluated and the modules developed with different data requirements for different resolution levels; (3) parameters to establish necessary and sufficient conditions for fish habitats need to be more fully identified; (4) ecological simulation should be incorporated into the IFG models; (5) both intensive and extensive validation of the methodology should be sought. (For example, <u>intensive testing</u> should be undertaken in regions where large data bases exist, such as salmonid streams of the Pacific northwest. <u>Extensive testing</u> should cover a range of physiographic provinces, i.e., comparing studies of eastern salmonid streams with western results, then extending to main stream rivers and non-salmonid species); (6) documentation of stream ecology over a broad spectrum of stream types and regions should be stressed; (7) reaches for study should be selected to ensure statistical reliability of data samples; (8) the methodology of computing weighted usable area should be replaced by a method using a histogram of volume units from which mean, median, percent of volume units with better than 50 percent desirability, etc. could be computed; (9) a general methodology should be developed by carefully assessing the variability of data over a range of stream types and geographic regions; (10) information derived from actual field conditions should replace habitat criteria now based on LD_{50} laboratory tests; (11) a regression approach should be used to describe behavioral response of a species to cover; (12) the proposed functional classification of macroinvertebrates should include indicator and keystone species; (13) a substrate index shoudl be used as long as it does not obscure the primary data; and (14) the present IFG Incremental Methodology should be modified to incorporate variables of stream biology and the state of the stream ecosystems as criteria for fish habitat.

To meet the need for understanding relationships between stream flow and recreation, the work by Anas, et al., 1979[1] on behavioral demand assessment was referenced by the instream recreation module. Key concepts extracted from the work includes: (1) recreation behavior is complex, voluntary, and discretionary, which suggests that it may be quite sensitive in sometimes unexpected ways to environmental change; (2) response of recreationists to stream flow may vary by activity and by market segment; (3) some impacts may be more important than others depending upon the market setments and phychological outcomes affected; (4) impact on psychological outcomes may occur without obvious changes in manifest behavior; and (5) the state-of-the-art of explaining relationships between environmental conditions and recreation behavior and benefit is primitive. While hydraulic measurement and simulation may be well developed in terms of proven theories and standard methods and measures, this is not so for prediction of recreation behavior.

The workshop raised several questions and criticism of the incremental methodology. The criticisms are: (1) the attempt to assess the impact of hydraulic characteristics of stream flow on certain instream recreation activities is, at present, too narrow in scope; (2) the methodology has been inadequate in examining the structur of recreation, i.e., the likelihood that

1_/ See reference of Module IV--The Relationships Between Recreation and Instream Flow of this report.

for different types of people, there may be different reactions to stream flow, even for a given activity; (3) the methodology needs a greater capability of delineating those stream flow variables which affect different types of activities and kinds of peole; (4) the criterion methodology now used is the "probability of use" function. However, true probabilities do not exist in the way the methodology is now constructed and it is not known what even is being predicted; and (5) the methodology does not include sufficeint concern for social welfare values.

The strengths of the incremental methodology identified by the workshop on recreation are: (1) it uses quantitative standard measures which have general validity and applicability; (2) its approach is based on efficient description of stream conditions through sampling and simulation; (3) an analytical approach is used, which promises to allow efficient and rigorous investigations of the issues; (4) the methodology to be theoretically and conceptually rigorous has created an articulation of precise questions as well as demands for specific information and operational definition of terms; (5) it has generated a new set of questions for tributary disciplines including recreation scientists, fish biologist water quality experts, and stream hydrologists; and (6) it has generated a program of developmental education. However, the IFGIM has not as yet achieved its objective of providing a capability of (1) assessing the recreation potential of a stream; (2) specifying instream flow requirements for recreation; and (3) assessing the impact on recreation potential of instream flow.

To achieve the above objective, the workshop lists four general components which must be more fully understood: (1) the relationship between recreation potential and instream flow--the criterion component, (2) the description and prediction of the instream flow characteristics of a given stream--the <u>resource description</u> component, (3) the user of the criterion component to measure and interpret the effect on recreation of the instream flow characteristics described or predicted for a given stream--the <u>evaluation</u> component, and (4) the practical <u>question</u> that needs to be answered--the <u>application</u> component.

The principle challenge to the <u>incremental methodology</u> is in the <u>criterion</u> component, where there are inadequacies with respect to (1) substantive knowledge about recreation, and (2) methods to formulate and apply criteria. The principle problem is to develop ways to <u>measure</u> and <u>interpret</u> the meaning of stream flow to recreation. There are five principle needs: (1) the nature and structure of recreation, vis-a-vis instream flow needs to be specified; (2) the need for a more rigorous definition of "recreation potential"; (3) for each recreation "species" there is a need to identify those parameters of or related to stream flow which are of significance; (4) the need for a "criterion methodology", i.e., a framework or strategy for constructing and applying criteria; and (5) the need to understand the processes by which instream flow affects recreation potential.

In response to the need to establish a more rigorous conceptual framework of relationships between recreation and instream flow, the workshop includes as an appendix a paper authored by Dr. George Peterson, entitled, "The Relationship Between Recreation and Instream Flow".

THE IFG INCREMENTAL METHODOLOGY

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Introduction

Instream flow requirements, often called instream flow needs, are the amounts of stream flow necessary to sustain instream values at an acceptable level. By instream values we mean the uses made of water within the stream channel. These include such traditional uses as navigation, hydropower generation, and waste load assimilation (water quality). In addition to these more established uses, fish and wildlife needs; riverine based recreation; compact and treaty requirements at downstream points of diversion; fresh water recruitment to estuaries, and consumptive requirements of riparian vegetation and floodplain wetlands are emerging as potent competitors for stream flows.

In addition to satisfying delivery schedules of downstream appropriators (water right holders), an ideal stream flow management plan should provide an "additive flow requirement" and a "complimentary instream flow requirement." Hence the total stream flow requirement for a given stream reach at a particular time is the sum of (1) the delivery requirement to satisfy

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downstream water rights, (2) an additive flow requirement to offset consumptive uses enroute, and (3) the complimentary instream flow requirement (Fig. 1).

The most desirable total stream flow requirement is one that will satisfy several uses at once. Understandably, at a given location on a given stream, only certain uses may be relevant, or preferential consideration may be given to the use(s) regarded as most important. But in either event stream flow is apportioned through negotiation and compromise. A paramount concern in these deliberations is the ability to analyze the acceptability of incremental changes in stream flow with respect to a particular use.

Instream flow assessments have traditionally arrived at a single threshold value for the fishery resource - "a minimum flow." Such an instream flow recommendation was usually determined solely from an analysis of hydrologic records, and provided only a limited opportunity for negotiation. This approach is based on the mistaken assumption that only flows below this "minimum" will be detrimental to the fishery resource. As a result of the fallacies and weaknesses associated with traditional fishery assessments it was apparent that better methods were required.

The IFG incremental methodology is a major advance in this regard for it attempts to quantify the amount of potential habitat available for each life history stage of a species as a function of stream flow. This method is intended to be used as a decision-making tool and is specifically tailored to demonstrate the impact of incremental changes in stream flow on fishery habitat potential.

The Incremental Methodology is intended to be used in those instances where the flow regime is the dominant determinant of the quality of the instream fishery or recreation resource and where hydraulic conditions are

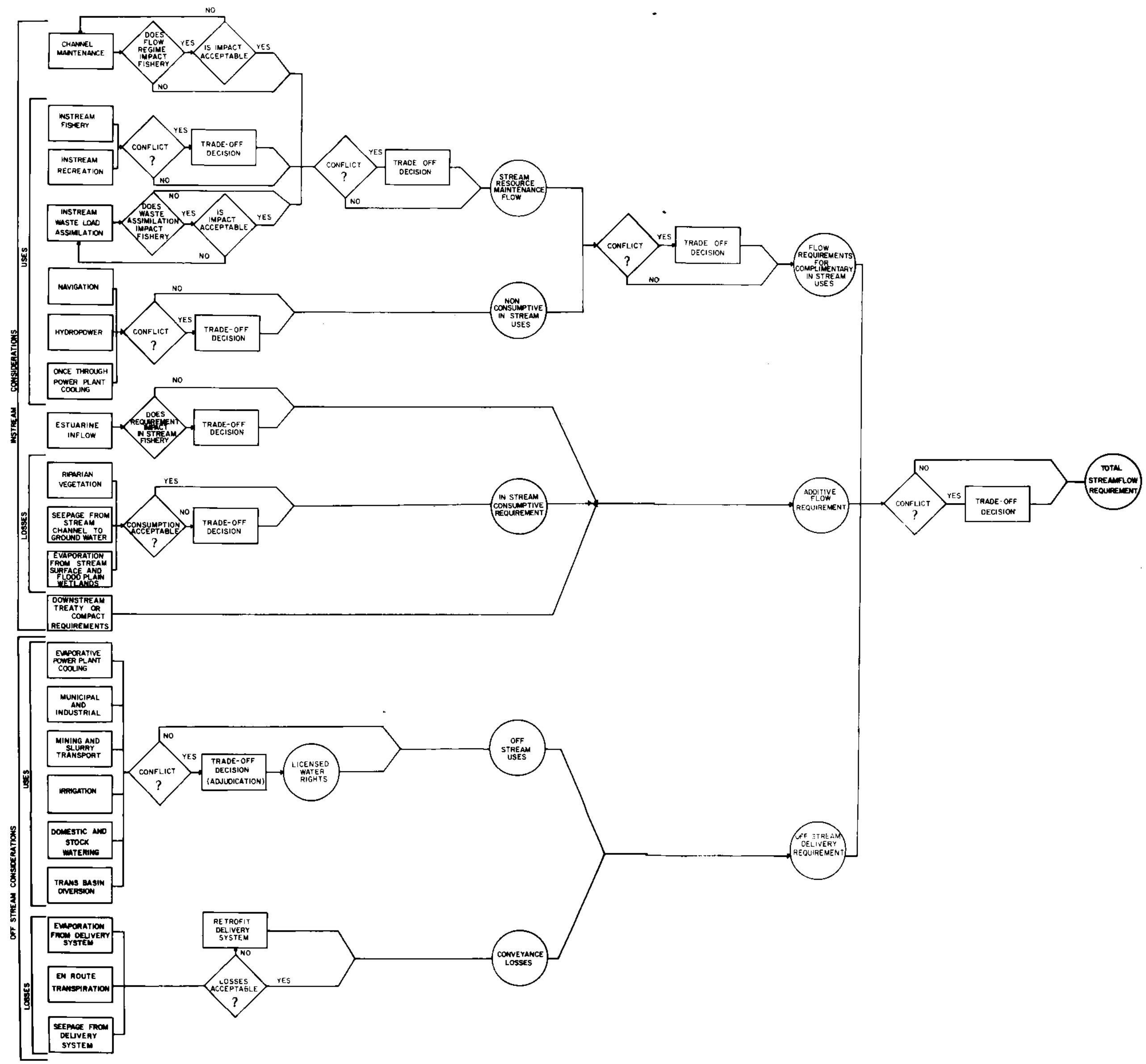


Figure 1. Flow chart of the decision-making process to develop a comprehensive stream flow management plan.

compatible with the theoretical basis of the models (i.e. steady flow within a rigid boundary). This method is composed of four basic components: (1) field measurement of stream channel characteristics using a multiple transect approach; (2) hydraulic simulation to determine the spacial distribution of combinations of depths and velocities with respect to substrate and cover objects under alternative flow regimes; (3) application of habitat suitability criteria to determine weighting factors; and (4) calculation of weighted usable area (gross habitat index) for the simulated stream flows based on physical characteristics of the stream.

Four primary variables can be identified which determine the character of instream habitat conditions: (1) water chemistry; (2) food web relations; (3) flow regime; and (4) channel structure. Associated with each of these major variables are the respective subsets of variables which interact to provide the myriad of physical-chemical conditions to which the stream biota respond. These four primary variables also offer a logical division for approaching the task of quantifying the effects of land and water management decisions on instream fishery resources.

During the 18 months preceding this workshop the Instream Flow Group's efforts concentrated on describing cause-effect relationships between stream flow alterations and instream fishery habitat potential. In western streams the most direct relationships (habitat constraints) are attributable to flow regime and/or channel structure. Consequently, hydraulic simulation modeling is of central importance to the incremental methodology.

Study Site Selection

Time and financial resources are seldom adequate to support the field work necessary to document stream flow-habitat relationships throughout an entire stream. Therefore, it is important to select study sites which are both characteristic of the stream, and capable of providing pertinent information. Either of two approaches to study-site selection can be utilized with the incremental methodology; (1) critical reach, and (2) representative reach.

Under the critical reach concept the study site is selected on the basis of its restrictiveness, i.e., stream flow characteristics at the critical reach are limiting attainment of the full potential of the instream resource. Associated with the critical reach concept is acceptance of the assumption that adequate stream flow through the critical reach will provide for satisfactory stream flow conditions throughout the remainder of the stream.

The critical reach concept implies that rather extensive knowledge of both the stream (hydrology, water-quality, channel geometry) and the instream resource (species composition, life history, passage requirements) exists. One must be satisfied that conditions at the selected study site(s) are, in actuality, limiting the instream resources potential. It should also be recognized that critical reaches only provide information specific to a particular set of questions; thus little opportunity would exist to utilize the critical reach data base to address questions pertaining to other instream uses.

A fisheries manager might select a critical reach on the basis of migration blockages, overwintering areas, or essential spawning and rearing habitat. In the case of endangered species, critical reaches might be selected on the basis of a unique combination of microhabitat conditions which are quite unrepresentative of the general riverine habitat type. With regard to instream recreation potential, a critical reach might be chosen on the basis of safety, access, or passage. The critical reach concept might also be used to evaluate such other instream concerns as: navigation, waste assimilation, or sediment transport.

The representative reach concept reflects recognition of the importance of the structure and form of the entire stream in sustaining a particular instream resource. Application of the representative reach concept is appropriate when limited life history information is available on the target species, or when limiting stream channel conditions (critical reaches) cannot be identified with any degree of certainty. The representative reach concept is also the more appropriate approach for analysis of species interactions or complimentary instream uses.

Two essentials of study site selection using the representative reach approach are homogeneity and randomness. Initially, the stream must be divided (stratified) into rather homogeneous segments based upon biological community structure, stream channel morphology, stream flow regime, and human activities. These stratified river segments are then sub-divided into populations of candidate representative reaches by either implicit or explicit zonation techniques (Bovee and Milhous 1978), and three or four candidate reaches are randomly selected from each of the respective populations of candidate reaches. Following this office work using maps and aerial photos, an on-site inspection is made of the candidate reaches to confirm that they are generally representative of the river segment(s) being evaluated. The actual study site(s) is then chosen from among the three or four candidate reaches on the basis of access, manpower and financial resources, and the limitations and safety of field personnel. What must be kept foremost in mind is that the representative reach is chosen for its ability to provide pertinent information regarding a given set of questions for the entire stream segment which it represents. Relationships defined between streamflow and physical habitat conditions at the study site are considered to be indicative of interactions existing throughout that river segment.

Application of the Methodology

The incremental methodology is intended to be used in those instances where the amount of streamflow is the dominant determinant of the abundance of a target organism and the determination of a streamflow requirement is a central question. It is also understood that streamflow conditions are compatible with the theoretical basis of the hydraulic models (i.e., steady flow within a rigid boundary) and that the habitat suitability curves are acceptable indications of an individual species preferred habitat conditions.

Once it has been determined that flow regime is the dominant driving variable and the study site(s) has been selected, standard surveying and stream measuring techniques are employed to obtain calibration data for IFG's hydraulic simulation models. Transects are placed to characterize both hydraulic and instream resource (fishery habitat) conditions. Detailed information is obtained on the stream channel geometry and hydraulic conditions using a multiple transect approach for microhabitat description. A discussion of the theory and field techniques associated with the Instream Flow Group's hydraulic simulation models can be found in Bovee and Milhous (1978).

Computer programs are available which use these data to predict hydraulic parameters (depth and velocity) with respect to any described substrate condition for any desired flow regime. The hydraulic model is calibrated to reproduce water surface elevations and horizontal velocity distributions observed at selective stream flow conditions. The IFG's simulation models normally use stream channel geometry and velocity data from several cross sections within a relatively short stream reach. Each transect can be subdivided into as many as 100 cells (conveyance areas) to facilitate detailed analysis of the spacial distribution of depth and velocity combinations. Once properly calibrated, the computer program will calculate the water surface evaluation and respective horizontal velocity distribution at each transect for all desired discharges. The simulated water service elevations and velocities are then passed from the hydraulic model to IFG's HABTAT model (Main 1978a).

Within the HABTAT model, the mean depth of each cell is computed by subtracting stream bed elevations from the simulated water surface elevation. Surface areas associated with the occurrence of various combinations of depth/velocity values are calculated by multiplying the width of the cell by the sum of half the reach distance to the next upstream and the next downstream transects. This procedure is illustrated in Figure 2.

The stream reach simulation takes the form of a multi-dimensional matrix showing the surface area of cells having various combinations of physical habitat characteristics (i.e., depth, velocity, substrate, and cover when applicable). Table 1 illustrates a depth-velocity matrix. The number in the upper lefthand corner of the matrix refers to 195 square feet of surface area per 500 feet of stream length having a combination of depths less than 1.0 feet and velocities less than 0.5 ft./sec. This represents the summation of the surface areas of all the individual cells within the simulated reach with that combination of depth and velocity. This 195 square feet of surface area is not necessarily contiguous.

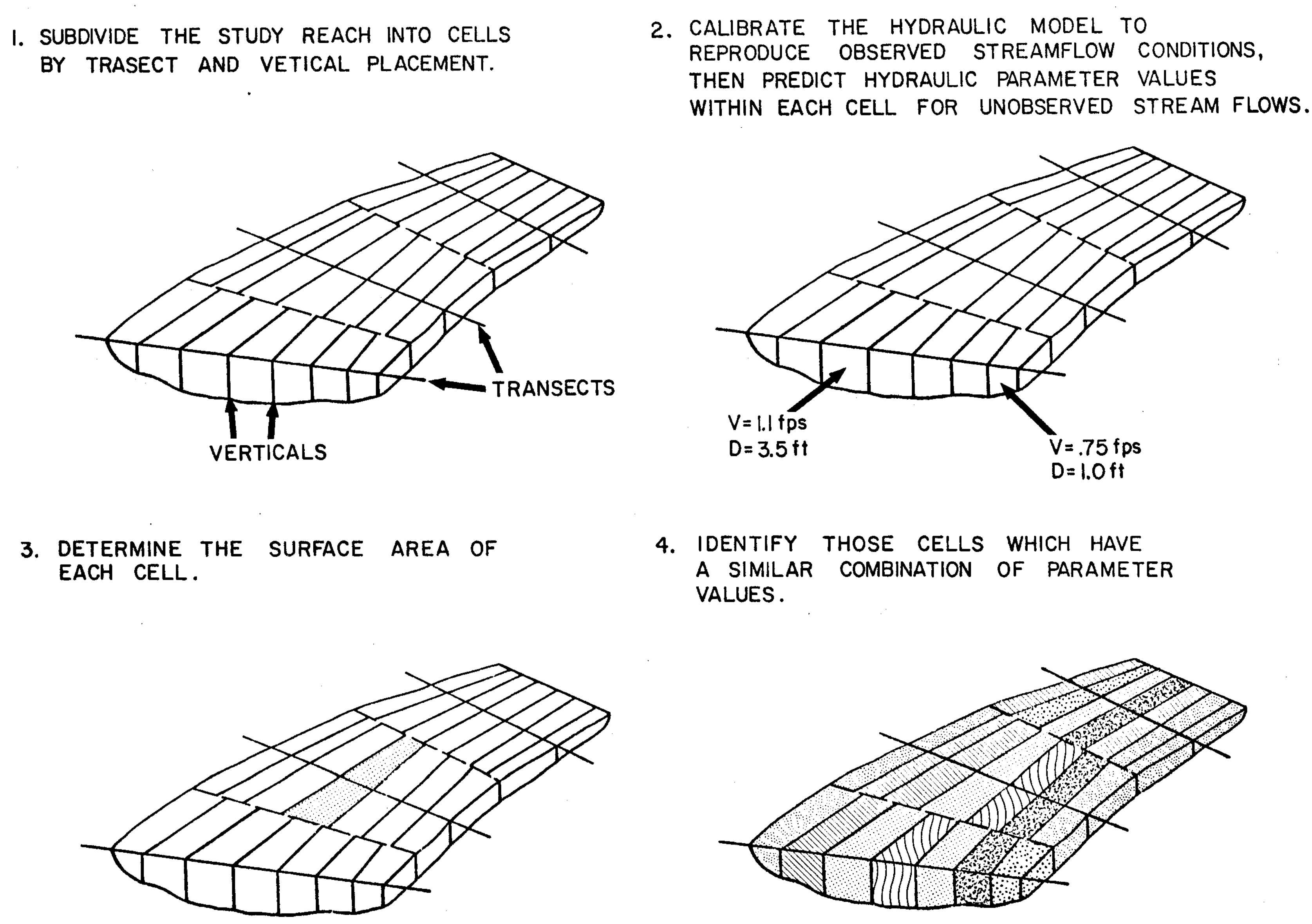


Figure 2. Identification of available combinations of hydraulic conditions within the simulated stream reach.

Table 1. Occurrance of different combinations of depth and velocity, expressed in square feet of surface area per 500 feet of stream reach. Discharge = 800 cfs.

Depth (ft.)	VELOCITY IN FEET PER SECOND .5	.5-.99	1.0-1.49	1.50-1.99	2.0-2.49	2.5-2.99	3.0-3.49	3.5	Row Totals
1	195	26	--	--	--	--	--	--	221
1.0-1.5	90	47	--	41	17	6	6	93	300
1.5-2.0	29	38	32	44	108	79	38	172	540
2.0-2.5	6	29	23	9	111	131	143	175	627
2.5-3.0	6	15	55	79	41	64	41	105	406
3.0-3.5	9	17	15	12	32	3	149	--	237
3.5-4.0	9	20	--	17	47	17	82	--	192
4.0-4.5	--	20	--	11	50	35	17	--	133
4.5-5.0	--	11	--	5	115	20	--	--	151
5.0-5.5	--	--	--	7	23	15	--	--	45
5.5-6.0	--	10	--	--	31	20	--	--	61
Column Totals	344	233	125	225	575	390	476	545	2913

In order to translate changes in stream hydraulics into impacts or effects on fish habitat it is necessary to identify describable relationships between appropriate hydraulic parameters and the target species or target group of species. Assemblege of such an information base was undertaken in 1977 by the IFG staff utilizing existing data from the scientific literature and files of state fishery management agencies. Four techniques were used to develop a preliminary information base in the form of two dimensional curves (originally called probability-of-use curves and as suggested during the workshop now called habitat suitability curves) describing species preference for a particular stream flow parameter. (Bovee and Cochnauer 1977).

These criteria[2] were prepared by life history stage for those streamflow parameters directly influenced by changes in flow regime or channel geometry and which were considered to most directly affect fish distribution; depth, velocity, substrate and temperature. Species criteria for the Salmonid fishes were developed and distributed by the Instream Flow Group in 1978 (Bovee 1978).

The habitat suitability curves used in conjunction with the IFG methodology are based on the understanding that individuals of a species tend to select the most favorable conditions available within a stream for habitation, but will use less favorable conditions with less frequency eventually leaving an area if possible before conditions become lethal. Subsequently individuals would be most frequently observed (sampled) in nature inhabiting their most preferred habitat conditions. Implicit in the use of these criteria is the assumption that frequency of observation is, in fact, indicative of habitat preference and the understanding that the data base used to construct the curves was obtained in an unbiased manner.

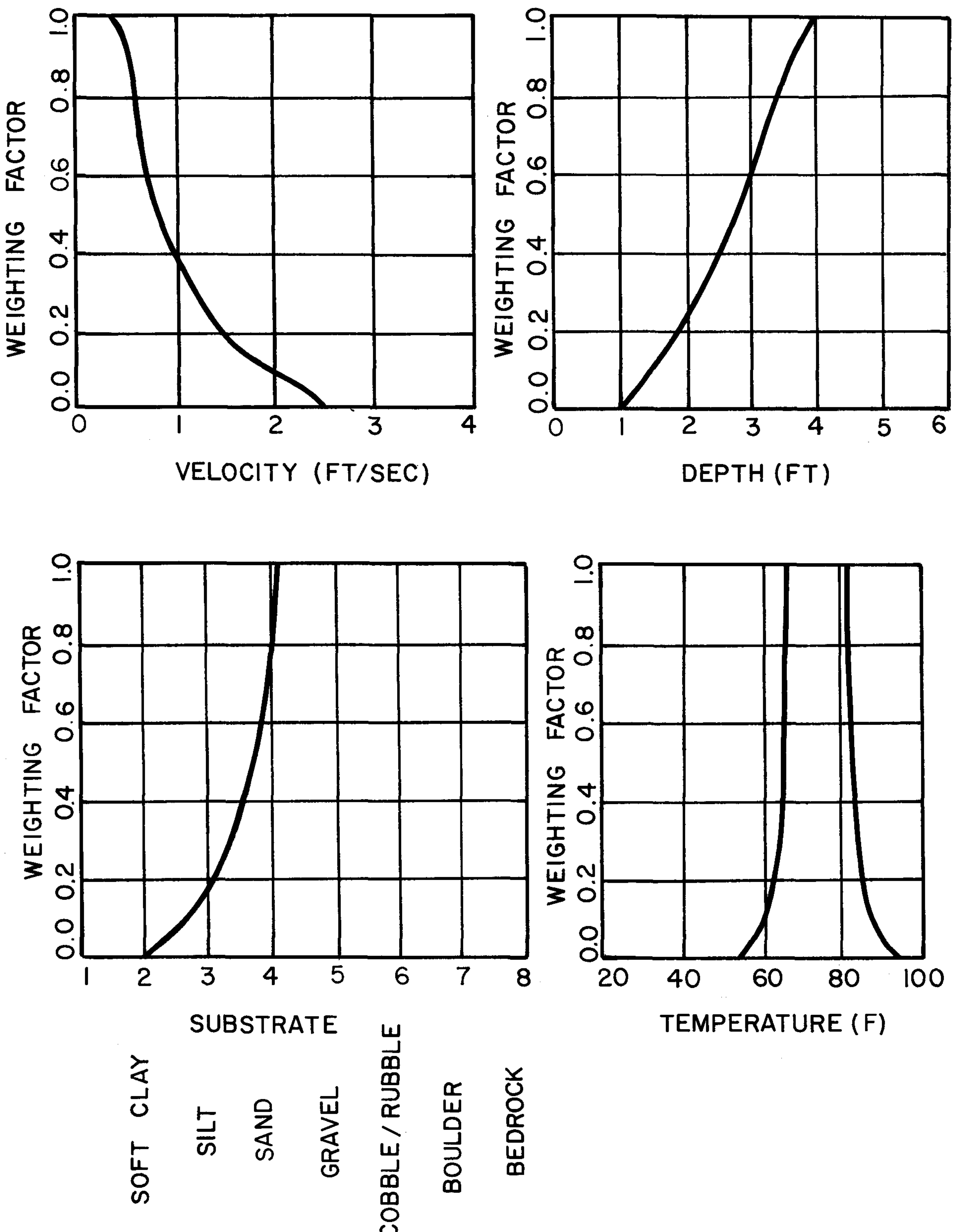
Figure 3 presents example criteria for adult smallmouth bass. For a given parameter value a weighting factor may be determined directly from the curve. For example, a depth of 2.4 feet and a velocity of 0.6 ft./sec. yield respective weighting factors of 0.37 and 0.80. The composite weighting factor (C) for a cell with the depth of 3.5 feet and a velocity of 0.5 by adult small mouth bass is (0.37 x 0.80) or 0.3.

[2] Editors note: Prior to the workshop being reported on in this proceedings these species criteria curves were referred to as probability-of-use curves. However, it became apparent during the course of the workshop discussions that these curves needed to be renamed. Several names have been considered but the one chosen for use is "Habitat Parameter Suitability" curves.

Figure 3. Habitat Suitability Curves for

Adult Smallmouth Bass

(clear water)



Substrate and temperature may also be incorporated into this analysis following similar procedures. If the temperature associated with the above combination of depth and velocity were 75° F, it would have a weighting factor of 1.0; were the substrate sand, the numeric index would be 4 and its associated weighting factor 0.80. The composite weighting for that combination of depth, velocity, temperature, and substrate would be (0.37 x 0.80 x 1.0 x 0.80) or 0.24.

Weighted usable area is defined as the total surface area having a certain combination of hydraulic conditions, multiplied by the composite weighting factor for that combination of conditions. This calculation is applied to each cell within the multidimensional matrix and is then summed. This habitat index in its simplest form is described in equation 1.

$$WUA = \sum_{i=1}^{n} C_i A_i \qquad (1)$$

where:

WUA = weighted usable area

C_i = composite weighting factor for usability

A_i = surface area of a cell

n = total number of cells within the simulated stream reach.

This procedure roughly equates the total surface area of the simulated reach to an equivalent area of optimal (preferred) habitat. For example, if 1,000 square feet of surface area had the aforementioned combination of depth, velocity, temperature, and substrate it would have the approximate habitat value of 240 square feet of optimum habitat (1000 ft^2 x 0.24).

An example of a two-dimensional matrix (depth and velocity) is presented in Table 2.

Table 2. Calculation of weighted usable area for adult small mouth bass based upon the distribution of depth and velocity from Table 1, and criteria presented in Figure 3 for a Discharge of 800cfs.

VELOCITY IN FEET PER SECOND

Depth (ft.)	.5 [.75]	.5-.99 [.90]	1.0-1.49 [.98]	1.51-1.99 [.98]	2.0-2.49 [.73]	2.5-2.99 [.13]	3.0-3.49 [.03]	3.5 [0]	Row Total
1 [.05]	195 (7.3)	26 (1.2)	--	--	--	--	--	--	221 (8.5)
1.0-1.5 [.12]	90 (8.1)	47 (5.1)	--	41 (4.8)	17 (1.5)	6 (0.1)	6 (0.0)	93 (0)	300 (19.6)
1.5-2.0 [.16]	29 (3.5)	38 (5.5)	32 (5.0)	44 (6.9)	108 (12.6)	79 (1.6)	38 (0.2)	172 (0)	540 (35.3)
2.0-2.5 [.22]	6 (1.0)	29 (5.7)	23 (5.0)	9 (1.9)	111 (17.8)	131 (3.7)	143 (0.9)	175 (0)	627 (36.0)
2.5-3.0 [.27]	6 (1.2)	15 (3.6)	55 (14.5)	79 (20.9)	41 (8.1)	64 (2.2)	41 (0.3)	105 (0)	406 (50.8)
3.0-3.5 [3.3]	9 (2.2)	17 (5.0)	15 (4.9)	12 (3.9)	32 (7.7)	3 (0.1)	149 (.15)	--	237 (25.3)
3.5-4.0 [.42]	9 (1.6)	20 (7.6)	--	17 (7.0)	47 (14.4)	17 (0.9)	82 (1.0)	--	192 (32.5)
4.0-4.5 [.53]	--	20 (9.5)	--	11 (5.7)	50 (19.3)	35 (2.4)	17 (0.3)	--	133 (37.2)
4.5-5.0	--	11 (7.4)	--	5 (3.7)	115 (63.0)	20 (2.0)	--	--	151 (76.1)
5.0-5.5 [1.0]	--	--	--	7 (6.9)	23 (16.8)	15 (2.0)	--	--	45 (25.7)
5.5-6.0 [1.0]	--	10 (9)	--	--	31 (22.6)	20 (2.6)	--	--	61 (34.3)
Column Total	344 (24.9)	233 (59.6)	125 (29.4)	225 (61.7)	575 (183.8)	390 (17.6)	476 (4.2)	545 (0)	2913 (381)

Weighting factors (ref. Fig. 3) for the depth and velocity ranges used in the matrix are enclosed in brackets. The upper numerals in the matrix refer to the surface area of the stream per 500 feet of reach which possesses that combination of depth and velocity (ref. Table 1), while the numerals in parenthesis refer to the equivalency in weighted usable area ($WUA_i = C_i A_i$). Note that in this example the total surface area per 500 feet of reach (2913 ft^2), has been equated to 381 ft^2 of surface area possessing most suitable depth-velocity conditions.

Using the IFG's hydraulic simulation models, one can readily generate velocity depth matricies for unobserved streamflow rates passing through the study site. With these new velocity-depth values at hand, the compilation procedure is repeated to obtain weighted usable area values for the streamflows being simulated. As a result, weighted usable area can be displayed as a function of streamflow for each life history stage of the target species (Fig. 4).

Given the necessary streamflow records, weighted usable area may be presented as a function of mean monthly flow rates. Such a display facilitates comparison of changes in habitat potential between average and drought year conditions (Fig. 5), or demonstrating impacts of streamflow withdrawal (diversion) on a selected life history phase (Fig. 6).

For purposes of project planning, one may find it desirable to compare weighted usable area fluctuations under pre and post project conditions. Figure 7 presents such a time series comparison of anticipated trends and fluctuations in weighted usable area. In this example, weighted usable area values attributable to September streamflow conditions are compared. However, weighted usable area values for any critical period could serve as a basis for such a comparison.

Figure 4. Weighted Usable Area vs.
Discharge for Smallmouth Bass at study site xxx

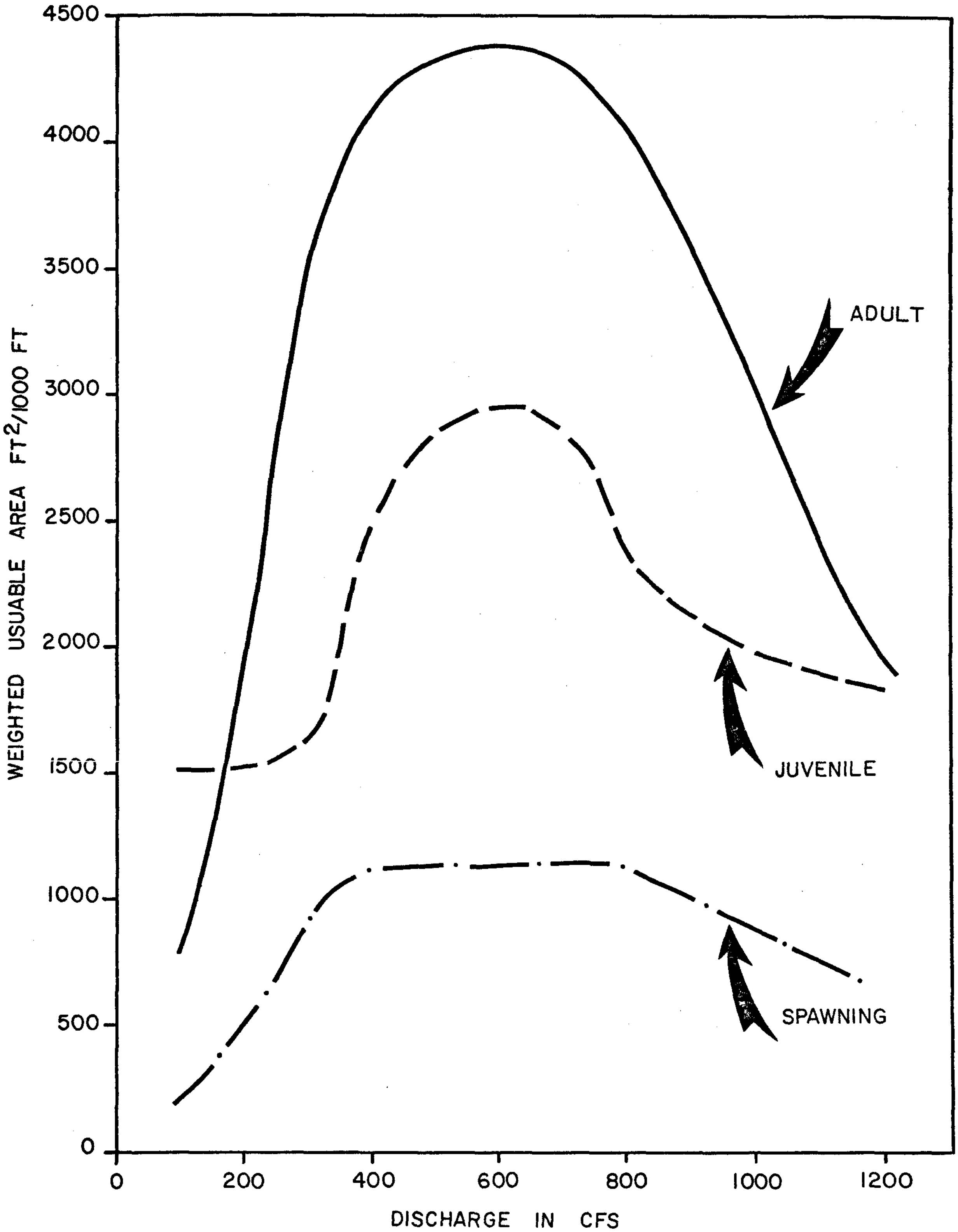


Figure 5. Monthly Weighted Usable Area Values for Adult Smallmouth Bass under Median and Drought year flow conditions

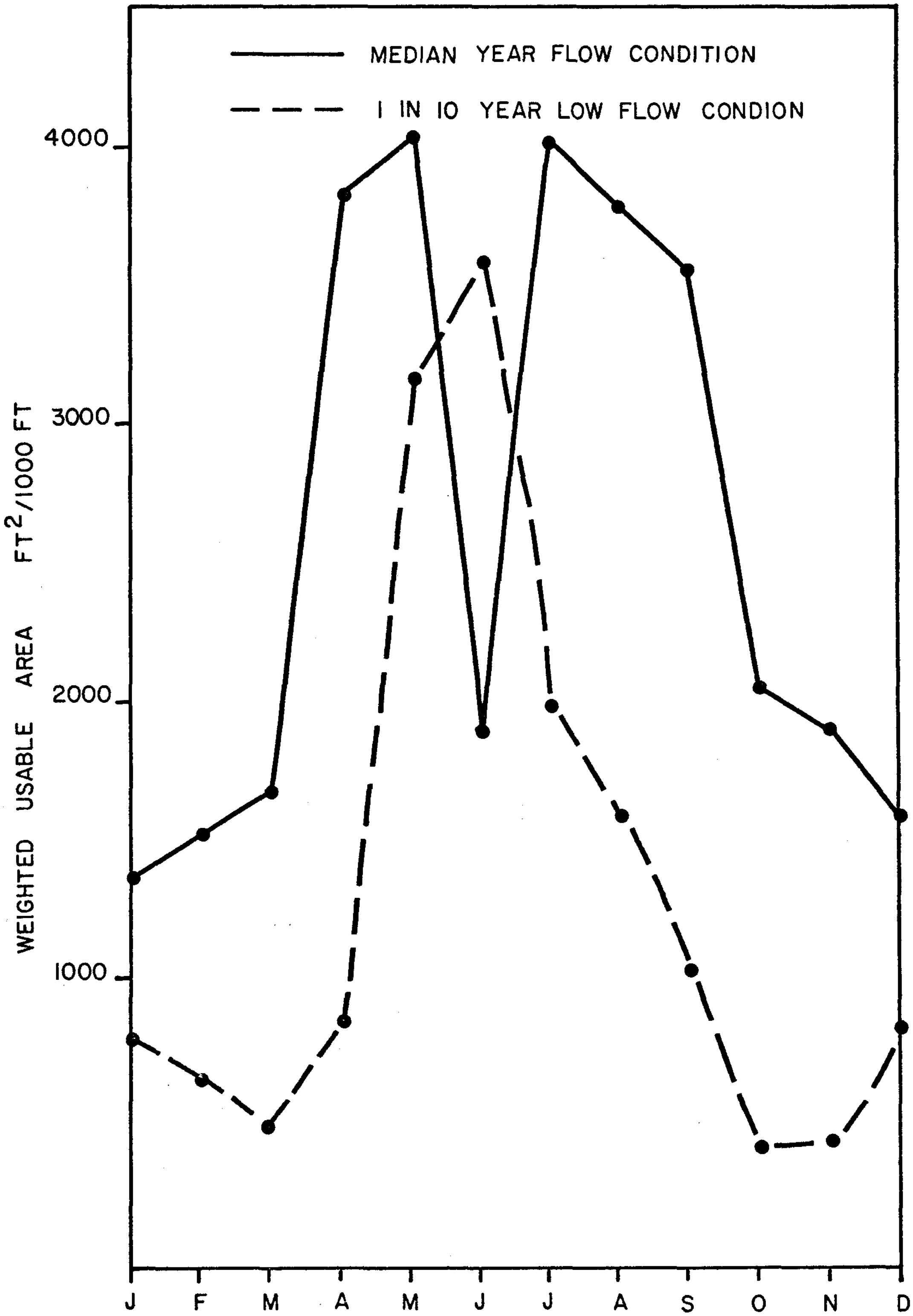
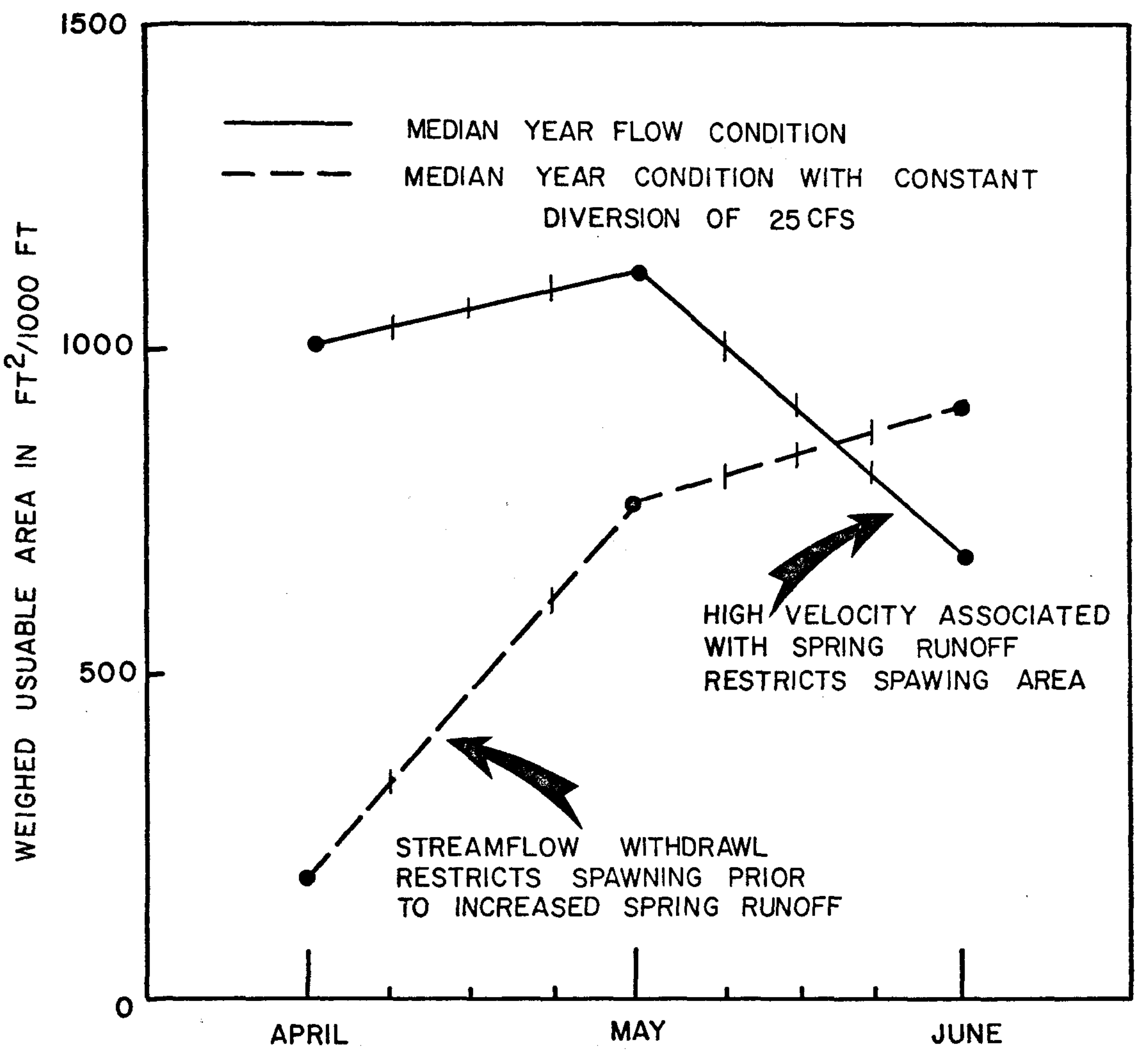


Figure 6. Effect of a constant stream flow withdrawal on available spawning area for smallmouth Bass at study site xxx.



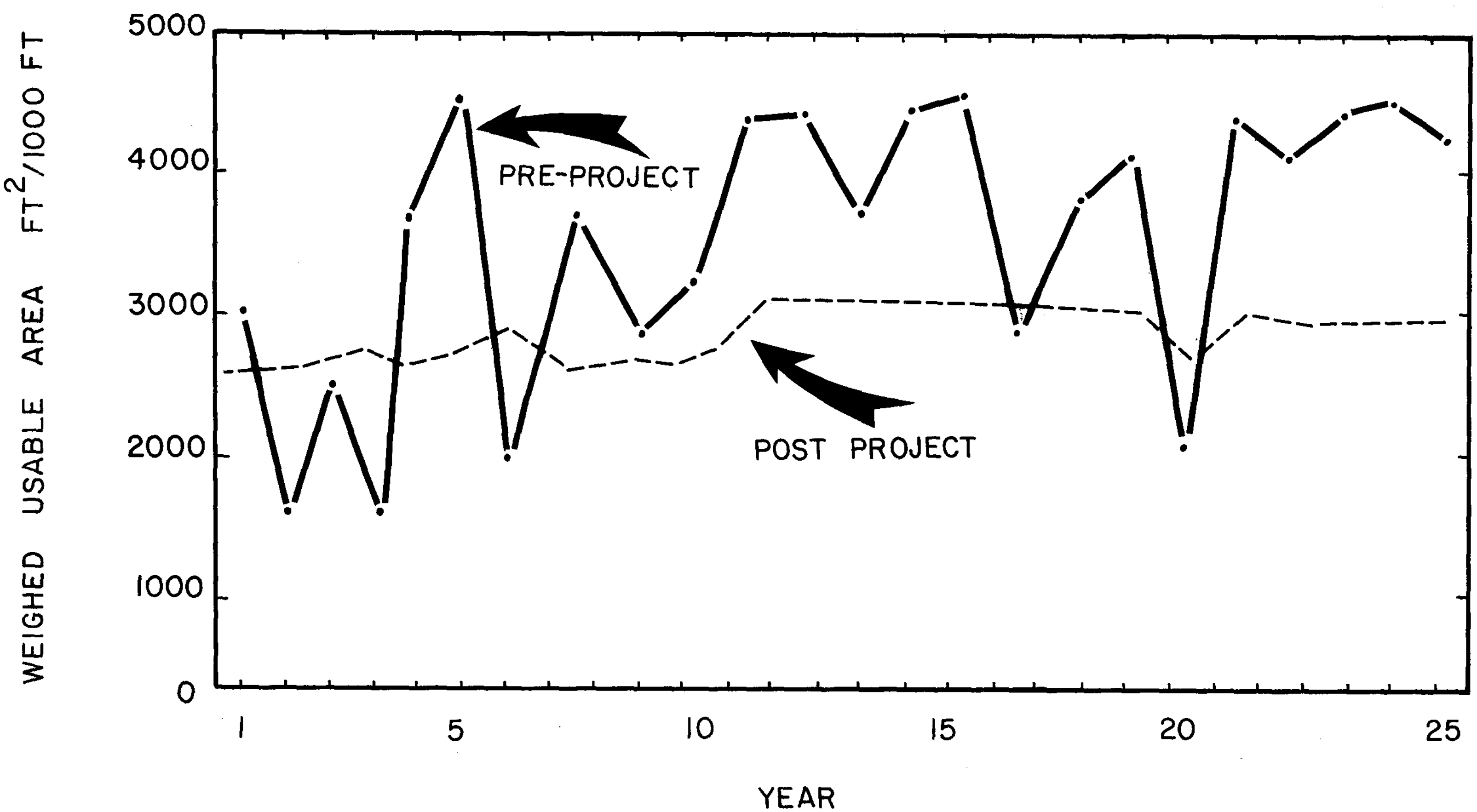


Figure 7. Comparison of Weighted Usable Area for Adult Smallmouth Bass during September at study site xxx projected for pre and post project conditions.

In summary, the IFG Incremental Methodology was developed as a decision-making tool for use in the water allocation arena. It links various elements of fisheries behavior science and open channel hydraulics in an attempt to describe the effects of incremental changes in streamflow on the instream fishery potential. The methodology may also be used to identify effects of stream channel alterations on fish habitat conditions or to predict possible shifts in species composition as a result of flow or channel changes.

The methodology is intended for use in those situations where the flow regime is the major determinant controlling the fishery resource and field conditions are compatible with the under-pinning theories and assumptions of the methodology: 1) steady state flow conditions exist within a rigid channel and, 2) individuals of a species respond directly to available hydraulic conditions. If these assumptions can reasonably be made, the methodology has application to three basic types of questions.

1) Quantification of Instream Flow Requirements
   a) Area wide planning
   b) Reservation or licensing of water rights
2) Negotiation of Water Delivery Schedules
   a) Minimum releases
   b) Yearly flow regimes (normal vs dry year conditions)
3) Impact Analysis
   a) Streamflow depletion
   b) Streamflow augmentation
   c) Channel alterations

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MODULE I: RIVER MECHANICS, MORPHOLOGY, WATERSHED PROCESSES

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Module Purposes

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Regression
Lumped Parameter
Physical Process

B. Three Math Approaches
Analytical
Finite Difference
Finite Element

C. IFG's Hydraulic Modeling

III. TEN CRITERIA FOR USEFUL MATH MODELS

1) Temporal Resolution - Short and Long Term
2) Spacial Resolution - Big and Little Systems
3) Widely Applicable
4) Sensitive to Management Activities
5) Climatic Extremes Handled
6) Data Collection Techniques
7) Oriented to Managment Personnel
8) Easily Transferable
9) Use Modular Approach
10) Documentation

IV. WATERSHED SYSTEMS AND SEDIMENT TRANSPORT

V. HIERARCHIAL APPROACH

I. INTRODUCTION

The river and watershed system is an integral part of the dynamic ecosystem. Stream flows, sediment transport rates, and channel morphology reflect the major responses resulting from watershed management and/or river utilization activities. Knowledge of river mechanics, morphology, and watershed management is basic to assessing instream flow needs.

Instream flow issues often result from increased competition for off stream water uses (agricultural, industrial, urban, and energy developments) and public concern for environmental quality. Sources of these issues arise from such development activities as: (1) the redistribution of water over time and/or space to increase low flows and/or reduce flood flows, (2) the construction of diversions which decrease natural stream flows, and (3) changes in land use or other watershed management practices that alter the water and sediment input to the stream. Such developments affect both water quantity and quality and in turn change stream morphology, stage-discharge relationships, substrate distribution, and fish habitat.

When assessing instream flow requirements for fishery habitat and instream recreation, knowledge of the spatial and temporal distribution of flow depths and velocities is necessary. Consequently, the Cooperative Instream Flow Service Group has developed hydraulic simulation techniques for the determination of the spatial distribution of various combinations of depths and velocities with respect to substrate for alternative flow regimes or channel configurations.

The purposes of the Watershed and River Mechanics Module of the Workshop were to: (1) evaluate current predictive methodologies, (2) evaluate the hydraulic components of the Instream Flow Group's Incremental Methodology, that are utilized for determining management aspects of instream flow needs, (3) suggest possible improvements to the IFG's hydraulic simulation models, (4) make recommendations pertaining to the analysis of sedimentation aspects of instream flows, and (5) recommend needed research.

A major objective was to be "critical."

II. BACKGROUND

General

The increasing interest in instream flow as a component of land and water resource planning has stimulated the development of particular and general watershed and river system response models. The models, whether physical or conceptual, are formulated to estimate physical quantities that describe the major system responses to precipitation such as: water yield, sediment yield, yields of other water pollutants and stream morphology.

Degradation, aggradation and movement of sediment and other pollutants in watersheds and river systems are closely related to water movement predictive streamflow and water routing models have received the most intensive study. Yet, the ability of the majority of available stream flow and water routing models to relate wildland management activities in rather unique environments in such a manner as to account for spatial diversity is not well demonstrated.

There are numerous mathematical models available for predicting the response of watersheds and river systems. A comprehensive review of nonpoint source water quality modeling in wildland management was conducted by the U.S. Forest Service in (1976). An assessment of available methodologies for the determination of instream flow requirements was made by Utah State University for the U.S. Fish and Wildlife Service (Stalnaker and Arnette, 1976). This assessment provided an in-depth review of basic stream flow measurements and relationships, water quality relationships to flow, methodologies for determining required instream flows for fish and other aquatic life, methodologies for assessing instream flow requirements for wildlife, and other measurement techniques for quantifying recreation and aesthetic values. Most of the methodologies identified in these publications have been studied by the IFG staff and provide the basis for much of the reasoning behind their Incremental Methodology.

Mathematical Models

Generally speaking mathematical models can be classified according to their dominant traits as one of three types: (1) regression, (2) lumped parameter or "black box" simulation, or (3) physical process simulation.

Regression models are often easy to use and understand but have limited applicability. A general weakness of regression models is that the variables representing water and land uses and instream flow conditions are often not specific enough to reflect the effects of many individual management activities. In addition, the regression models usually require sufficient observed data to correlate meaningful relationships. This is often their most serious drawback. Furthermore, it is very difficult to predict time and space dependent responses (requisites of any instream flow analysis) using regression equations. Regression models are very useful, however, for identifying significant variables in large complex systems.

The lumped parameter or "black box simulation type of model interprets input-output relationships using simplified coefficients and formulae which may or may not have any physical significance. The classic example of a lumped parameter model is the rational formula for estimating peak discharge.[1]

Such a model is easy to use, but has limited physical meaning and is often inaccurate. It is impossible to reliably predict the effects of alternative mixes and sequences of land management activities occurring in upland watersheds utilizing lumped parameter models.

Physical process simulation models avoid "lumping" physically significant variables. The overall physical process is separated into component processes which themselves can be analyzed and refined to meet the needs of the user. Consequently, as each process component is better understood and upgraded, the overall model becomes more representative of the physical system. Use of components also allows input of variables that have physical significance and meaning to the user. Advantages of physical process simulation models over other types of models are numerous. But most importantly physical process models are "dynamic simulation systems"; the input variables are physically significant and the model need not be stationary in either time or space.

Methodologies presented in the literature identify three basic types of mathematical approaches to watershed and river analysis: (1) the analytical solution, (2) the finite difference method, and (3) the finite-element method. Hann and Young (1972) and Simons et al. (1977) provide a good summary review

[1] Q=CIA where Q is the peak discharge, I is the rainfall input, A is the drainage area, and C is the runoff coefficient which represents the major hydrologic processes.

of finite difference models using both implicit and explicit solution techniques. Analytical solutions are usually limited by some simplifying assumption (i.e. one dimensional steady flow in rigid boundaries) and are, therefore, applicable only to those field conditionsfor which the simplifying assumptions are valid.

More recently finite-element techniques have been actively applied to microscopic flow phenomena. Due to the fundamentals of the finite element formulation, completely arbitrary geometrics can be modeled as well as more common conditions. In addition, the feature of variable element size can be used to create a fine mesh of elements in areas of high variable gradient in order to obtain the desired accuracy and detail in sensitive regions. The major drawback of the finite-element method is the required computer time. This constraint will be less significant in the future as numerical techniques and computer software advancements occur.

IFG's Hydraulic Simulation Efforts

To date the IFG has developed two hydraulic simulation models. The hydraulic component of the Incremental Methodology is specifically oriented toward the assessment of riverine fishery conditions on a microhabitat basis. The models determine spatial distribution of various combinations of velocities and depths with respect to substrate as a function of either discharge or cross sectional geometry. Basically, the IFG's hydraulic models are "analytical" and are based on the assumptions of steady-state flow and rigid boundary conditions. A major effort is made in determining stage-discharge relationships and calibrating the Manning roughness coefficient based on site specific fiedld data (i.e. collected within the representative reach. IGF's hydraulic models represent progressive, state-of-the-art tools for evaluating instream flow needs. The calibration techniques used are described in two reports Hydraulic Simulation in Instream Flow Studies (Bovee and Milhous, 1978) and The Calibration of Equations Used to Calculate the Velocity Distribution in a River for Instream Flow Analysis (Milhous, 1977).

The IFG-2 model is an "analytical physical process" model. It is a modification of the Bureau of Reclamations water surface profile model (Bureau of Reclamation 1957 and 1968). The IFG model utilizes standard step backwater computational procedures, but differs from its predecessor in that the stream channel may be subdivided into as many as ninety-nine conveyance areas rather than the more traditional "main channel"; "right and left overbank" subdivisions. Continuity is maintained from transect to transect using the average velocity and total cross sectional area.

Resistance coefficients (i.e. Manning's "n") are difficult to estimate. Quite often, the streams of primary interest to fishing managers have channels in which the resistance coefficients vary marked by. In general, these coefficients are a function of channel shape, bed material size and distribution, flow depth and vegetation. Resistance to flow also changes markedly with discharge as bedform, bed material, or boundary conditions change. To reduce dependence on properly estimating resistance coefficients, channel shape, velocity distribution, and water surface elevations are measured in the field under different flow conditions. These data are then used for site specific calibration of the hydraulic model.

The IFG-4 model is an "analytical regression" model, dependent upon empiricism. This model is based on a stage-discharge concept and requires that repetitive depth-discharge and velocity-discharge observations be made at the study site throughout the entire range of flows of concern. Equations for velocity ($V=aQ^b$)and stage ($S=cQ^d$ stage zero flow) are fitted to the data sets then used as a basis for interpolating between observed flow conditions.

The watershed and river are integral parts of a dynamic system. Natural variations and man's activities alike often cause significant shifting of stage-discharge relationships. These shifts result from: (1) the sediment movement that modifies the cross section continuously, (2) the dynamic effects due to the rising and falling of stream discharge, and (3) the alteration of bed material size and distribution (substrata). The rate of change of stage-discharge relationships is dependent on the characteristics of the river system such as: the bed material size, the magnitude and duration of flow, the channel geometry, the gradient of the channel, and geological or man-made controls. However, for relatively stable channels the stage-discharge relationship remains comparatively constant and the IFG-4 model is applicable. For unstable or dynamic systems, the IFG-4 model is not valid.

The Instream Flow Group's (IFG) efforts have been oriented toward the development of a hierarchial and modular approach to instream flow studies utilizing physical process simulation modeling. The modules and various models available within the modules, should be considered as "building blocks" from which an analysis framework can be constructed to evaluate effects of a wide range of management alternatives. The existing hydraulic models (IFG-2 and IFG-4 represent operational state-of-the-art tools for instream flow assessment work. Yet, they are applicable only to those field conditions for which conditional assumptions hold.

III. CRITERIA FOR USEFUL MATHEMATICAL MODELS WITH SPECIFIC COMMENT ON THE IFG INCREMENTAL METHODOLOGY

General Criteria

In order for a methodology to be useful, it should possess the following attributes:

- (1) Promote clarity, not complexity. Application of complex techniques to a rather simple problem will confuse rather than clarify the solution.

- (2) Produce believable results. The methdology should be based on accepted state-of-the-art techniques. When complex techniques are appropriate they should be applied.

- (3) Reduce, not compound, the risk and uncertainty associated with solution alternatives.

- (4) Provide understandable results. Results should be presented in a format that can be understood by user/audience groups alike.

During the course of the workshop this discussion group identified ten criteria as being descriptive of a useful mathematical model for predicting cause-effect relationships within watershed and river systems. These criteria were used to evaluate the IFG's methodology. A summary follows:

Criteria 1: Temporal resolution of the methodology should be both short- and long-term. Management practices usually have short- or long- term effects on the environment, and the short-term projects may have prolonged effects. Therefore, operationally the IFG methodology falls short of this mark. The hydraulic simulation models being used by the IFG are based on the assumption of rigid boundary conditions. With respect to a water-shed response or project-life time frame this assumption is seldom met. It is important to recognize that a river is a dynamic system. An alluvial river is continuously changing its position and shape as a consequence of hydraulic forces acting on its bed and banks. These changes may be slow or rapid and may result from natural events or from man's activities. Available information and technique for predicting watershed response due to natural variation and man-made activities should be incorporated in the methdology.

Response to stream flow is presently based on monthly flows. Monthly flows cannot adequately represent the natural variation in most river systems due to the averaging process. The prediction error caused by the monthly averaging process is even more pronounced when sediment transport is evaluated. A better approach to watershed response due to duration, quality, and frequency of flow is needed to improve prediction. In addition, the impacts of forest harvesting, irrigated agriculture, grazing, mining, and other watershed management activities on the water and sediment yield from watersheds to the stream channel need to be considered.

Criteria 2: Upland management plans and activities very often occur in small watersheds while legal and institutional interests in instream flows are often focused well downstream in the watershed or river basin. As a consequence, <u>the spatial resolution of the IFG models should accommodate both small and large watersheds and river systems</u>.

As previously stated the current methodology does not consider any watershed responses. The existing IFG hydraulic models are theoretically and operationally applicable to both large and small streams. However, it is not clear how reliable they are in quantifying actual habitat conditions in large rivers. In part, this is a criteria problem. But it is also unrealistic to assume that mean column velocity provides sufficient resolution to adequately quantify micro habitat conditions in large deep rivers. hence, alternative hydraulic models should be developed which analyize vertical velocity distribution.

Criteria 3: <u>The method should be widely applicable</u>. That is, although the model parameters may be locally or regionally specific, the model itself should not be. Conceptually, the IFG's methodology is capable of providing an appropriate cause effect linkage between management practices and system response in a variety of geographic locations.

Operationally, the models require site specific calibration data and regionally specific species response critera. Lack of such a data base may well impede the transfer and application of the methodology, however, the same general logic and modeling approach (methodology) would be applicable from one region to another.

Criteria 4: <u>The model should be sensitive to desired management activities</u>. It must be possible to explicitly represent management activities and simulate the system response resulting from these activities.

The methodology is intended to be used as a decision making tool and is specifically tailored to demonstrate the impact of alternative flow regimes on instream habitat conditions. The method also has application for evaluating stream channel alteration or relocation proposals. From an operational standpoint the incremental methodology can be applied to three fundamental types of instream flow questions.

1) Quantification of Instream Flow Requirements
    a) Area wide planning
    b) Reservation or licensing of water rights
2) Negotiation of Water Delivery Schedules
    a) Minimum releases
    b) Yearly flow regimes (normal vs dry year conditions)
3) Impact Analysis
    a) Streamflow depletion
    b) Streamflow agumentation
    c) Channel alterations

Conceptually the methodology has far greater potential. By developing modular components discussed under criteria one, it will be possible to initiate quantification of the effects of numerous land management activities on instream fishery habitat and recreational potential.

Criteria 5: <u>The uncertainties due to varying climatic and spatial input should be considered</u>. The simulation must consider variations in both mean values and extreme events which requires a probabilistic approach to describe the stochastic structure of model inputs.

The existing IFG methodology is capable of handling the full complement of hydrologic input (streamflow records) available. The method readily assesses changes in habitat potential attributable to "incremental" changes in streamflow. Given ample streamflow data the IFG models are capable of generating stochastic time series plots of corresponding instream fishery habitat conditions.

A notable strength of the method is the ability to describe instream conditions with respect to local climatic events such as: wet, average and drought conditions.

Criteria 6: <u>The model should be developed within the constraints of available data</u>. Models intended for practical applications should not impose requirements for data that are excessively difficult, costly, or time consuming to collect or acquire. If a large quantity of data is required, an effective data storage and retrieval system is necessary.

Calibration data for the hydraulic models may be obtained by employing routine surveying and stream gaging techniques.

Criteria 7: <u>The model should be oriented for use by management personnel</u>. Models intended for use by managers must fit into the specific decision-making processes and situations for which they are to be employed, if information resources are to be generated efficiently and used effectively. So, for useable models to be designed and implemented, developers must be in effective communication with target users throughout the development process. Involving users in model design helps insure that the model developer has full knowledge of the decision-making environment, the actual problems mangers face, and the user's perception of the situtation being modeled. Such a model will be more relevant and the user will better trust its validity and capability. The perspective of the water manager is foremost in the IFG's model development work. Emphasis is on building a communication tool between the fishery manager and water-planning community. By involving users in model design IFG helps insure that the Group has full knowledge of the decision-making environment, the actual problems both managers face, and the user groups' perception of the everyday utility of the software being developed.

Criteria 8: It should be possible to easily transfer the model to different levels of accuracy and resolution. Models operable at several levels of accuracy and resolution will be required in order to provide the full range of tools needed for instream, land and river management.

Providing useable and realistic models and guidelines for use by field level managers in many cases will first require developing and testing relatively complex process models. Once the processes invloved are thoroughly understood and the sensitive parameters identified, these models can then be regionalized and generalized to provide simplified models and guidelines for field users.

The IFG has incorporated a hierarchial approach within the framework of its methodology. A very low resolution hydraulic analysis can be performed with extremly limited field data. Investment in the manpower and materials necessary to obtain real world calibration data over a range of flows will greatly improve the accuracy of the predictions obtained from the hydraulic models and upgrade considerably the confidence one has in the hydraulic analysis (i.e. a function of discharge). Depending upon the financial and temporal resources available a corresponding level of hydraulic analysis can be performed. Precautions must be taken, however, not to enter into litigation or important negotiations with a reconnassiance grade simulation.

Criteria 9: <u>The model computer software system should adopt the modular approach</u>. Adopting the modular approach offers an opportunity to build a coordinated nucleus of standardized system components for use in a wide spectrum of watershed and river systems. This nucleus would be made up of components that are necessary for storage and retrieval, analysis, and display. Modular systems also have the advantage that individual components can be updated or replaced as needed without disrupting other components of the system. Generalized, all-purpose models are expensive to develop, usually lack sensitivity to the wide range of management alternatives, are difficult to use and control, and have large data requirements--all of which tend to detract from their operational utility.

As stated previously the IFG methodology utilizes a modular approach to assessing instream flow requirements. Although this approach may appear confusing, and perhaps even ambiguous, to the uninitiated it possesses several distinct advantages over generalized all purpose models; even with their standardized data input and crank turning "cook book" instruction.

Adopting the modular approach offers an opportunity to build a coordinated nucleus of standardized system components for use in a wide spectrum of instream flow situations. This nucleus would be made up of component "building blocks" that provide for common interfaces for information transfer between modules that are necessary for storage and retrieval, analysis, and display. In addition, modular systems have the great advantage that individual components can be refined, updated, or replaced as needed without disrupting other components of the system.

Criteria 10: The models should be properly documented. The documentation should include: i) the sytem level flow chart showing how modules and files are connected, ii) the flow chart of each module, iii) the description of each file, iv) narrative descriptions showing how the system is implemented, v) definitions of all variables in each module, and vi) comments on each program or file that show the purpose of the code.

From an operational standpoint IFG's computer software is not adequately documented for efficient transfer. In part, this is due to the lack of documentation which was available for those programs IFG obtained from outside sources and modified to fit the specific needs of instream habitat assessment work. As of this writing the IFG has four major software packages operational. User manuals need to be developed, flow charts prepared, and variables defied for each program. This is perhaps the IFG's biggest housekeeping chore.

The philosophy of modeling adopted by the IFG is consistent with these general attributes and criteria. The methodology is based on accepted state-of-the-art techniques, employing a hierarchial and modular approach to simulation modeling. Obvious it is the intent of the IFG to utilize simulation to promote clarity, reduce risk, and otherwise facilitate decision making.

IV. WATERSHED PROCESSES AND SEDIMENT TRANSPORT

State-of-the-Art

Existing sediment models of watershed systems deal mainly with surface erosion. No process models exist for unstable channel erosion, nor are any models available for predicting mass wasting and its interaction with channels. Almost all existing surface erosion models are based on either the Musgrave approach or the Universal Soil Loss Equation (U.S. Forest Service, 1976). These models are difficult to use because they are insensitive to both the spatial and temporal variability of management activities. In 1975, Simons et al. (1975a) developed a numerical model to simulate the physical processes governing sediment movement on small watersheds. This model can predict the effects of management activities on sediment yield in both time and space. However, its applicability is presently limited to surface erosion on fairly stable land in small watersheds and for a single storm.

Sediment transport is often one of the most important variables needed for evaluating fishery habitat. The capacity of a stream to transport sediment depends on hydraulic properties of the stream channel. Such variables as slope, roughness, channel geometry, discharge, velocity, turbulence, fluid properties, and size and gradation of the sediment are closely related to the hydraulic variables controlling the capacity of the stream to carry water, and are subject to mathematical analysis.

Generally, an alluvial river is continuously changing its position and shape as a consequence of hydraulic forces acting on its bed and banks. As a result of the interaction of these forces biological processes within the river environment are in a constant state of flux. These changes may be slow or rapid and may result from natural events or from man's activities.

When a river channel is modified locally, the change frequently causes modification of channel characteristics both up and downstream and can be propagated for long distances. Many available river routing models either neglect the dynamic response due to sediment movement or are insensitive to man's activities. Because bed material is transported as both suspended load and bed load the different physical laws governing these modes of transport must be incorporated into any method for predicting total transport of bed material.

The distinction between bed-material load and wash load is of importance. Bed material is transported based on availability and the capacity of the stream. Its transport rate is functionally related to measurable hydraulic variables. Wash load is not usually transported at the capacity of the stream and is not functionally related to hydraulic variables. While there is no sharp demarcation between wash load and bed-material load, one rule of thumb assumes that the bed-material load consists of sizes equal to or greater than 0.062 mm, the division between sand and silt. Another reasonable criteria is to choose a sediment size finer than the smallest 10 percent of the bed material as the point of division between wash load and bed-material load.

Sediment particles that constitute the bed-material load are transported either by rolling or sliding along the bed (bed load) or in suspension. Again there is no sharp distinction between bed load and suspended load. A particle of the bed-material load can move part of the time in contact with the bed or be suspended by the flow. Generally, the amount of bed-material moving in contact with the bed of a large sand-bed river is only a small percentage of the bed material moving in suspension. These two modes of transport follow different physical laws which must be incorporated into any equation for estimating the bed-material discharge of a river.

Limited quantities of fine material moving as wash load usually will not pose direct problems inhibiting development activities in the riverine environment. However, large concentrations of fine materials can influence fluid viscosity and density, stream bank stability, growth of aquatic plants, and the biomass of the channel.

For a detailed treatment of currently used suspended and bed-material load transport theories refer to Vanoni (1976) and Simons and Senturk (1977). Data on sediment transport in the steep channel systems is generally unavailable due to the extreme difficulty associated with collecting data in the laboratory and field environments. Yet many of the streams with high fishery and recreation potential are steep turbulent channels. An effort to obtain more information on sediment transport in the steep channel systems is warranted.

Hydraulic geometry is a general term applied to alluvial channels to denote relationships between discharge, the channel morphology, hydraulics and sediment transport. In self-formed alluvial channels, the morphologic, hydraulic, and sedimentation characteristics of the channel are determined by a large variety of factors. In general, these relationships apply to channels within a physiographic region and can be derived from data available on gaged rivers. It is understood that hydraulic geometry relationships express the integrated effect of all the hydraulic, hydrologic, meterorologic, and geologic variables in a drainage basin.

Geometric relations describing alluvial streams are necessary in river engineering and river modeling. The forerunners of such relationships are the regime equations developed to design stable alluvial canals. A generalized version of hydraulic geometry relations was developed by Leopold and Maddock (1953) for different regions in the United States and for different types of rivers. In general the hydraulic geometry relations are stated as: $W = a\ Q^b$; $y_o = c\ A^f$; $V = k\ Q^m$; $Q_T = p\ Q^j$; $S = t\ Q^z$; $n = r\ Q^{yo}$, where W is the channel width, y_o is the channel depth, V is the average velocity of flow, Q_T, is the total bed-material load, S is the energy gradient, n is the Manning's roughness coefficient, and Q is the discharge. Leopold and Maddock (1953) have shown that in a drainage basin, two types of hydraulic geometry relationships can be defined: 1) those relating W, y_o, V and Q_T to the variation of discharge at a station, and 2) those relating these variables to the discharges of a given frequency of occurrence at various stations in a drainage basin. The former are called <u>at-station</u> relationships and the latter <u>downstream</u> relationships. Because Q_T is not usually available, Leopold and Maddock used Q_s the suspended load transport rate in their relations.

Utilizing the same governing equations in river and watershed modeling, Li et al. (1976) theoretically developed a set of hydraulic geometry equations. These relationships are almost identical to those proposed by Leopold and Maddock.

The at-station relations derived by Li et al. (1976) are:

$$W \sim Q^{0.24} \tag{1}$$

$$y_o \sim Q^{0.46} \tag{2}$$

$$S \sim Q^{0.00} \tag{3}$$

$$V \sim Q^{0.30} \tag{4}$$

Equation (3) implies that slope is constant at a cross section. This is not quite true except for steep channels. At low flow the effective channel slope is that of the thalweg that flows from pool through crossing to pool. At higher stages the thalweg straightens somewhat shortening the path of travel and increasing the local slope. In the extreme case, river slope approaches the valley slope at flood stage. It is during high floods that the flow often cuts across the point bars developing chute channels. This path of travel verifies the shorter path the water takes and that a steeper channel prevails during floods.

The derived downstream relations for bank-full discharge are:

$$y_b \sim Q_b^{0.46} \tag{5}$$

$$W_b \sim Q_b^{0.46} \tag{6}$$

$$S \sim Q_b^{0.46} \tag{7}$$

$$V_b \sim Q_b^{0.08} \tag{8}$$

where the subscript b indicates the bank-full condition. The above theoretically derived hydraulic geometry equations can be utilized to estimate bank-full discharge and to evaluate channel stability.

For a detailed description of current knowledge of river morphology refer to Schumm (1978) and Simons and Senturk (1977).

Aggradation, degradation, and the transport of sediment and pollutants in watersheds and river systems are closely related to water movement. A model that will predict effects of management activities and represent spatial and temporal variability of both activities and processes is needed. A great deal of research has been conducted on various components within the hydrologic cycle. This research in conjunction with stream flow and water routing models provide necessary ingredients for advanceing our understanding of physical process simulation for estimating transport rates of sediment and pollutants.

HIERARCHIAL APPROACH FOR ANALYSIS

Both general and specific criteria of useful models applicable to instream flow analysis have been previewed. This section discusses a multiple level of analysis approach that can be utilized for achieving selected levels of resolution. The IFG's methodology should consider watershed processes and sedimentation as integral components of the riverine ecosystem, and develop an analytical approach toward quantification. The recommended hierarchial approach for this analysis is presented by "watershed" and "channel" submodule discussion groups. Insight is provided as to the steps required to develop and conduct an integral analysis of watershed processes and sedimentation.

Watershed Submodule

A watershed submodule would provide water and sediment inflow (magnitude and timing) information for other components of the analysis. A recommended approach to multiple levels of analysis follows:

Level 1 analysis is limited to working with immediately available data and performing only "desk top" analyses. The available information would be analyzed using several mechanisms such as frequency distribution analysis, water yield nomographs, the geomorphic description of drainage patterns, etc. The analysis would then describe the present watershed conditions, with regard to frequency and duration of various flow volumes, both high and low. Such details regarding the flows would be based on description and evaluation of basin characteristics, stream patterns, soil types, land-use patterns, etc.

Level 2 analysis would extend and refine the level 1 effort to narrower confidence bounds and more completely describe the watershed and flow characteristics. Some field measurements would be required including stream cross sections, sediment size fraction surveys, and spot checks of stream flows. More extensive data manipulation and transfer mechanisms would be applied to obtain more accurate, location specific results.

Level 3 would use state-of-the-art models to perform the data manipulation and system description functions. Additional data specific to the site of interest would be collected as needed to provide the additional data needed to improve model accuracy.

Level 4 would involve research to upgrade and/or modify the state-of-the-art methods to improve the level 3 analysis.

The description of watershed, stream flow and sediment characteristics at each level of resolution is dependent on the following information: (1) location of the flow altering facilities within the watershed, (2) the purpose and methods of operation and impacts on flow imposed by such facilities, (3) the portion of affected watershed, i.e., to the main stem or to the estuary, and (4) the time span of alteration of physical and flow conditions.

The following table summarizes the type of information, type of manipulation and results obtainable utilizing the three levels of analysis.

Level 1: Approximate Confidence-±50%

Data	Manipulation	Results
Streamflow:		
USGS, county, state or other agency's gage data. Water hydrographs or stage hydrographs with stage-discharge relationships	Translation to specific site, then frequency analysis	Duration curve of daily discharge, frequency distribution, bank-full discharge (Q), date and duration of peak Q, duration of bank-full Q,
Precipitation:		
Nearest representative, USNWS gage or gages	Translation to site TP-40 and other intensity-duration analysis	Intensity, frequency, annual precipitation distribution, mean annual precipitation, etc.
Maps:		
USGS, county, state and other entities topographic and soil maps	Geomorphologic description of drainage pattern Water yield nomographs or computerized procedure	Basin characteristics, area, stream order, length, slope erosion potential, stream potential, soil types Average seasonal normalized runoff distribution, i.e., hydrograph based on 7-day averages
Areal photos:	Visual inspection and interpretation	Land use, vegetation, human impacts
Other reports and personal communications:		Any and all of above

Data	Manipulation	Results
Proposed Activity:		
Description of altering facility, modes of operation, location	Interpratation and judgement	Description of effects on downstream hydrographs, return flow, altered frequency distribution, altered duration curve, reduction in flushing, reduction in stream power, changes in habitat due to sediment, regrading and revegetation caused by altered flows
		General: description of trends and identification of problem areas meriting more intense study

Level 2: Approximate Confidence ±20%

Data	Manipulation	Results
All data of Level 1 plus some stream cross sections, travel time studies, and spot checks of flows calculated in Level 1	More sophisticated manipulation mechanisms to obtain results with greater resolution	Improved description of flow regime, better sediment supply description, explicit description of system trends and magnitude of impacts caused by alterations

Level 3: Approximate resolution ±10%

Data	Manipulation	Results
All Level 2 data plus place recording precipitation gages in the watershed, sample sediment, establish flow gage in reach of interest	State-of-the-art modeling used to manipulate data to most accurately describe basin phenomena; then utilize the models to access impacts caused by alterations	Same as Level 2 with smaller error bounds, and improved site descriptions

Level 4: Approximate Resolution ±10%

Use current models to identify short- and long-term data needs and research needs. Then conduct research to improve Level 3 analysis. The data needs, manipulation, and expected results are similar to Level 3 analysis.

Channel Submodule

If atream flow is to be altered with respect to water quality, river mechanics or watershed. Processes, channel submodule would deal with the river response utilizing river mechanics, sedimentation, and geomorphic principles. The first question is, "What inputs are needed and what can be said concerning (1) present instream conditions, and (2) changes and rates of changes caused by the altered flow system?"

Various levels of analysis can be formulated, verified and utilized depending on: level of accuracy required, available data, constraints, magnitude of projected channel changes, rate of channel changes, whether or not the channel is on the threshold of a major change considering its geometry and hydraulics.

Suggested Levels of Channel Submodule Analysis

Level 1--Office work and limited field investigations to estimate if significant channel changes may occur. This would require about one man-month of effort for a channel reach with a length of one mile.

Level 2--Conduct field work to establish baseline data (present conditions) and project changes that will result from alterations in flow, etc.

Level 3--Obtain additional data (some data could by synthesized) to utilize the present state-of-the-art methods to simulate changes continuously and/or for major events.

Level 4-- Conduct research to develop and/or modify state-of-the-art technology to improve Level 3 analysis. Might incorporate sediment routing by size fraction. This approach would utilize an interactive data storage and retrieval system and could include data essential for the analysis of water quality, biology, and recreation, etc.

Level 5--Incorporate the management model with Level 3 and/or Level 4 analysis as one component of the comprehensive system of models.

All levels of analysis should be capable of evaluating channel responses to all levels of stream flow alteration. The methods of analysis must include the stream system and the watershed. The data required and recommended level of analysis for various levels of analysis follow.

Needs	Data Required	Method of Analysis
Knowledge of present system Required data regarding: velocity, depth and substrate	Recorded data: climatic hydrologic hydraulic Maps Aerial photos Field data: type of river bank erosion stability bed and bank material vegetation channel geometry watershed characteristics riffle and pool sequence velocity geology controls structures Proposed structures water rights, etc.	Geomorphic, transport, hydrologic and hydraulic relations required for a qualitative analysis. An example is to use Lane relation (Simons and Senturk, 1977) hydraulic geometric equations, etc.

Level 2

Needs	Data Required	Method of Analysis
Requires more accurate and detailed data regarding: velocity depth substrate Also need more information on changes in above as function of space and time	All data for Level 1 plus: detail data on subreaches, cross sections in the subreaches, stage-discharge relations, suspended sediment, bed material, channel slope, etc.	Conduct Level 1 type study supported with additional data on sediment transport, geomorphic relations, stage duration, flow distribution, peak flows, minimum flows, etc. Determine more precise values of: velocity, depth, and substrate
	Information on: verticals at a cross section, substrate. engineering and natural controls, land-use changes, and watershed impacts. Decide whether to treat river as rigid or alluvial system.	If results indicate: 1. large changes in time and space 2. thresholds 3. high costs 4. need for greater accuracy 5. cannot satisfy legal, etc., constraints then go on to Level 3 analysis

Level 3

Use the current state-of-the-art models and techniques to route water and sediment for major events or continuously if necessary. Generally, a known discharge model will provide sufficient accuracy.

Develop methodologies to accomodate all interests including water resources development, water quality, recreation, biology, and river mechanics.

Develop and utilize a common data storage and retrieval system. Such an approach is necessary to conduct an accurate, economical, efficient and sufficient analysis.

Level 4

Use current models to identify short- and long-term data needs and research needs and then conduct research to improve Level 3 type analysis. One could proceed with a higher level of sophistication involving water quality, sediment routing by size fraction, two-dimensional modeling and improve watershed modeling components.

Multistep Development for Analysis

The development and application of a model usually involves the following steps: spatial design, temporal design, model formulation, mathematical solution, model calibration, parameter sensitivity analysis, qualitative examination of physical significance, model simplification, regionalization and generalization, validation, testing and refinement under operational field applications and documentation.

The spatial and temporal designs of watershed and river systems are both requisets for any realistic representation of the space-time structure of the system simulation models. The spatial design must consider the purposes of the study. Knowledge of pertinent gaging stations, structures, and confluences allows development of the spatial design of a large river basin. The watershed geometry, topography, vegetation and soil distribution may also be necessary.

The temporal design is used to generate input for evaluating system response, over time. The temporal design of a system can be made using the historic hydrologic records of the watershed and river basin. Such records include: historic maximums, minimums; mean precipitation, temperature, moisture content; river stages, precipitation patterns, flow volumes, and the effect of man's activities on the system. The temporal design should be compatible with the spatial design. Therefore, only those records pertinent to areas included in the spatial design need be analyzed.

After the spatial and temporal designs have been made, the physical processes governing the response of the system are not difficult to identify, and a series of partial or total differential equations can be used to represent the governing processes. The model formulation should consider the criteria of a useful mathematical model established earlier.

For simulating the dynamic response of water and river systems, perhaps the most important governing equations include: the continuity equation for water, the continuity equation for sediment, and the energy equation. These three equations can be solved simultaneously or can be approximated by solving the water continuity equation and the momentum equation first and then refine the solution by using the sediment continuity equation. The second approach is usually acceptable because the movement of sediment is much slower than that of water. The numerical solution of these three equations can proceed in two directions. Either an attempt can be made to convert the original system of ordinary differential equations by using the method of characteristics (Chang and Richards, 1971), or one can replace the partial derivatives in the original system with quotients of finite-differences by using the explicit method or the implicit method (Amein, 1968; Amein and Fang, 1970, and Chen, 1973).

In the mathematical modeling of system respones, the calibration of model parameters has often relied on an optimization scheme. The dependency on the optimization technique may be reduced if the model is formulated considering the physical significance of important processes. For the flood routing problem, the parameters describing flow resistance are usually unknown, but their ranges are known from measured data. However, the optimum values of the parameters which reproduce correct model response are usually not available. Hence, model calibration is a necessity. The simplest calibration technique is the trial and error method. Except for models that contain parameters with very narrow searching ranges, the trial and error procedure is inefficient. An efficient procedure is apparently needed for the model calibration. There are many optimization techniques available for the purpose of model calibration. However, the usefulness of a particular optimization technique is very dependent on the formulation of the model being calibrated. Rosenbrock's (1960) optimization technique is usually recommended for finding the optimum set of parameters because it is by far the most promising and efficient method for fitting a hydrologic model. Modifications of Rosenbrock's method have been made by Simons and Li (1976) to increase the efficiency of the method.

After development, the model should be examined by a parameter sensitivity analysis. This sensitivity analysis facilitates model parameter calibration, identifies data needs and provides useful information for model simplification. Another important examination is to examine the model to assure that it is meaningful considering physical significance and field experience. Lane's relation (Simons and Senturk, 1977) is very useful for qualitative analysis of river responses and is often used to provide a guide for examination of the mathematical model.

Simplification is a step backward from the more complicated process models that deal with time and space. In general, the more complicated time-space models solve finite difference formulations of the various processes at each time-space point. The simplified model retreats from this approach and averages the processes over both time and space. For most cases, however, the complex procedure provides the better solution.

The main disadvantages of the complex models is that they require computer applications and knowledge of the mathematical formulations and assumptions that are often beyond the capability of the average field user. The limitations of regression type of "black box" models and user restrictions imposed by the more complex physical process models have made necessary the development of simplified physical process component models. Such simplified models can provide the field user with an easy to use, accurate methodology for estimating system response (Simons et al., 1977b).

In order to facilitate application of the model, the regionalization of model parameters should be made. This can be achieved by extensive application of the model in various geographical areas. After regionalization has been completed, generalization of the model is possible and it may be applied to various regions. An example of regionalization and generalization is given by the Agricultural Research Service (1975).

The refinement of the model is a continuous process. As more field data becomes available, the model can be improved so that more accurate predictions are possible. The final step involved in model development is the documentation of the model.

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MODULE II: INSTREAM WATER QUALITY

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ABSTRACT

Members of Module IV (Instream Water Quality) suggest that a spectrum of water quality methodologies may be required to make incremental improvements to instream flow analysis. A series of four levels of analysis are suggested ranging from expert opinion to high level R&D assessments. The existing IFGIM can support levels 1 and 2 types of water quality studies for streams and small rivers, but a major change in methodology may be required to address impounded river systems and large rivers such as the Ohio, Missouri and the Mississippi. The critical problem at all levels is the lack of information on the levels of exposure and concentrations of chemicals that will cause damage to aquatic organisms. While improvements in the ability to predict the fate of chemicals and heat in low flow conditions can be realized at each level of analysis, the lack of criterion to define the response of aquatic organisms to water quality is a limiting factor.

BACKGROUND

The purpose of this module was to examine the existing components of the IFG Incremental Methodology (IFGIM) and suggest an incremental development that would introduce water quality aspects of instream flow needs. To be of any use, this development must be applicable to the specific problems that IFG expects to encounter. The problems are basically of two types: (1) the redistribution of water over a year (or periods of years) to increase low flows and/or reduce flood flows; and (2) the installation of major diversions upstream which decrease available flows. The context of these problems could be: (1) the need to establish instream flows as part of a long range planning process; (2) the need to make operational decisions on a real-time basis to maintain minimum low flows; and (3) the evaluation of EIS proposals that would change instream flows. No limit is specified for the size of a river system.

The existing components of the IFGIM are: (1) a hydraulic simulation of a stream reach; (2) determination of the spatial distribution of combinations of depths, velocities, and substrate within the reach; (3) application of weighting factors for each combination of depth, velocity, and substrate with respect to each species and life stage of concern; and (4) calculation of weighted usable area (WUA) by life stage of species for each flow regime or channel condition under investigation.

Not all module members examined the work performed by IFG in developing and applying the methodology. There was criticism of a theoretical nature and some disagreement as to the scope of applicability, but overall the IFGIM was considered to be a necessary first step in evaluating the impacts of flows on instream habitats.

GENERAL OBSERVATION

Existing Methodology

Members of this module on water quality were concerned over the implicit assumption made by the IFG in the development of their existing methodology. These concerns focused on the applicability of these methods to larger rivers and river systems with impoundments, and the claim that weighting factors used to determine weighted usable area (WUA) are not probabilities.

Objections were raised that the weighting factors used to determine WUA were referred to as "probabilities." Dr. Zison (1978) expressed the consensus feeling that the weighting factors, w, are developed simply from observed numbers of a particular kind of fish found under given conditions of velocity (or depth or substrate) normalized so that the maximum occurrence is equal to unity. Therefore, w does not represent a probability. A probability might describe the likelihood that one fish (or one or more fish, or so many fish, etc.) will be present for some set period of time within some set volume or region of stream under a given velocity (or depth or substrate). That is, it might express the likelihood that some concentration of fish in the stream will be equalled or exceeded some percent of the time.

Dr. Zison (1978) also expressed the concern of the module members regarding the concept of weighted usable area (WUA). The concern focused on the issue of continuity of usable stream segments. One speaker commented that "One hundred junkyards don't make one rose garden." The arrangement of WUA segments should be taken into account. For example, for fish habitat, 1,000 stream surface acres of longitudinally contiguous WUA out of a total area of 2,000 acres would probably be better than 1,000 acres broken into laterally oriented, non-contiguous segments. Also, 10,000 acres of w = 0.1 area (1,000 acres of WUA) may really not be equivalent to 1,000 acres of w = 1.0 area. Just how different they are, of course, determines how severe problems stemming from the assumption are likely to be. As values of w for two compared areas become more divergent, the comparison becomes increasingly tenuous. That is, to equate 8,000 acres of w = 0.9 with 9,000 acres of w = 0.8 is not as bad as 8,000 acres of w= 0.9 with 72,000 acres of w = 0.1.

Management Alternatives

It may be possible to reduce flows and not change water quality significantly if proper waste water and land management is observed. Before a methodology is discussed to predict water quality responses to flow alterations, an understanding of management alternatives to preserve water quality is important.

Even when flow is reduced in a river, there may be management actions that can be taken to maintain water quality. For example, diversion points could be selected at locations below rather than above waste water discharges. This would provide more water for dilution of waste, but would degrade the quality of downstream diversions. If a waste discharge of 100 cfs is located in a river with a low flow of 1000 cfs, the waste water would be diluted 10/1. A diversion of flow below the waste discharge would not impact water quality of the instream flow as significantly as if the diversion occurred just above the diversion. In the latter case, if 900 cfs were diverted, only 100 cfs would remain instream and the waste would only be diluted 1/1 or a factor of 10 less. The acceptance of this management alternative could contribute to the maintenance of water quality. The added cost of treatment to diverters could possibly be balanced by the reduced losses to instream flow users.

Reduction of instream flows will tend to increase water temperatures since water levels will fall and travel times will increase. In regions where diversions are for irrigation, return flows will be heated by the fields and in irrigation ditches and drains. Several management actions can be taken to compensate for increased exposure to the sun. The first alternative for small streams would be to increase the shading of the stream bed with vegetation or physically covering the channel. A recent experiment using branches to cover stream channels during clearing for highway construction was effective in the state of Washington. Another alternative would be to install covered ditches and drains for the last section of return flow discharges to the river to reduce heating. Finally, if the instream flows are subject to thermal discharges, it may be possible to float the hot water on top of the colder water rather than to mix the thermal discharge with the receiving waters. The higher surface temperature will dissipate the heat faster than with a mixed stream.

When water is impounded for release at future times, the upper waters (epilimnium) tend to warm and the lower waters (hypolumnium) tend to be depleted of oxygen. Some reservoirs may stratify and present water quality problems. By proper mixing of withdrawals from stratified impoundments, downstream water quality may be regulated. On the other hand, improper withdrawal of impounded waters can create severe downstream water quality problems.

Riparian land use can greatly impact water quality. The clear cutting of forest will expose streams to rapid heating, the urbanization of watersheds without adequate sewage systems will contribute significant amounts of oxygen demanding wastes and nutrients, and the industrialization of a river valley can contribute toxic materials in addition to the other wastes of urbanization and agriculture. Policies that preserve a green belt or natural buffer zone can be significant deterrents to water quality degradation in spite of flow reductions.

In cases where flow diversions cannot be denied, there are management practices that can be used to reduce the amount diverted. In certain areas of the western United States the use of unlined canals requires much more water than systems with lined canals because of high infiltration rates. Similarly, covered pipes would reduce evaporation losses. The key to increased agricultural efficiency of water use is economics. As long as the cost of water is low, there is not an incentive to install sprinkler systems or other devices that reduce water application to crops.

Prior to developing a position that flow must be retained to preserve water quality, all feasible management options must be examined so water quality enhancement may be an issue to be negotiated in return for instream flow reductions. It may be feasible to have better water quality in spite of lower instream flows.

Introduction of Water Quality Concerns

The objective of this module was to suggest means of introducing water quality aspects into the IFGIM. Historically, water quality analysis has been a fragmented field with researchers focusing on specific pollutants and specific aquatic organisms. For a given research effort, it was not currently possible in most cases to examine the fate of all pollutants on all compartments of an aquatic ecosystem. Efforts such as IBP encountered great difficulty in addressing such goals. A survey of methodologies available or under development indicates that engineers have developed analytical and empirical methods ranging from crude nomographs to complex computer models to estimate the fate of pollutants. Aquatic scientists have focused on more mechanistic approaches and tend to conduct two variable studies rather than holistic ecosystem analyses. These efforts suggest that it is possible to examine the fate of a single pollutant in great detail, but that the marginal value of such extensive study may not always be significant in water resource management studies. On the other hand the use of crude estimates of the fate of many pollutants to provide adequate information for management studies may receive strong criticism by the scientists conducting research of such pollutants.

In order for a methodology to be useful to the IFG, it should possess several attributes.

1) Promote clarity, not complexity. Applying complex techniques to a simple problem may confuse rather than clarify the solution.

2) Produce believable results. The methodology should be based on accepted state-of-the-art techniques. When complex techniques are appropriate they should be applied.

3) Reduce, not compound, the risk and uncertainty associated with solution alternatives. The techniques should be consistent with the objectives of the study and lead to specific conclusions. The study conclusions should contain something other than a recommendation for a bigger, more expensive, follow-on study.

4) Produce understandable results. Results should be presented in a format that can be understood by the people who need to use them.

There are numerous predictive techniques currently being used to evaluate water quality problems and they differ greatly in capability. The capability of a technique is established by two characteristics: 1) the number of constituents that may be included in a water quality study; and 2) the resolution (i.e., complexity and level of detail) of the analysis for each constituent. The resolution of a technique is related to the conceptual distribution of the constituent in time and space, and to the complexity of the mathematical functions representing the physical and biochemical properties of the constituent.

Dr. Lee expressed the concern that chemical concentration or water temperature should not be equated to "water quality." The evaluation of water quality as defined by Dr. Lee is the final task in the IFG when the outputs of the water quantity module, the ecosystem module, and this module are integrated to determine the response of fish to changes in water flow, chemical concentration, and the aquatic ecosystem. The purpose of this module is to suggest a series of increasingly precise methods to estimate water temperature and the concentration of selected chemicals in water. It is not the purpose of this module to evaluate the environmental significance of the presence of chemicals in rivers.

HIERARCHIAL FRAMEWORK FOR ANALYSIS

The introduction of water quality concerns to the IFGIM must be an evolutionary process that will improve as the staff develops skills in water quality analyses advances. While it may be possible to formulate a highly detailed and complex methodology that may be of great interest to scientists on the frontiers of water quality research, such a methodology may be too complex and impractical for operational decision making related to low flows. The members of this module have attempted to classify methodologies by their cost, required knowledge, data needs, and ability to resolve a basic low flow/water quality issue. There are four classes or levels of resolution suggested for water quality analyses. Tables 1 and 2 summarize the characteristics and utility of each level of resolution proposed. Level 1 can be classified as methods to provide low cost, crude estimates of potential water quality problems. These methods rely on text book concepts and heuristic approaches. They are low in cost and may stimulate debate among scientists that seek more refined analysis of water quality problems. Level 2 methodologies are more costly and will estimate changes in temperature and oxygen due to flow alterations within a factor of two. Level 3 methodologies expand the set of chemicals to be analyzed and attempt to employ state-of-the-art technology at still higher costs. Level 4 methodologies are research and development concepts that are attempting to improve the current state of knowledge.

While these methodologies are called water quality analyses they focus on the fate of physical and chemical pollutants in waters. Dr. Lee was very concerned that this module extend the methodology to speak to the issue of effects on aquatic organisms, rather than focus solely on forecasting that fate of pollutants in the receiving waters. Other members of this module were concerned that Level 4 methodologies are beyond the capabilities and interest of the IFG and that the thrust of the water quality efforts be placed on level 2 or 3 type methodologies.

Traditionally the analysis of water quality in a river system requires knowledge of all upstream activities since pollutants may not be completely assimilated when they enter a given reach. One of the objectives of a Level 1 or Level 2 analysis may be to examine an entire river system to identify reaches where low flow impacts on water quality may be most severe. Level 3 or 4 methodologies can then be used to improve the estimate of input in these critical reaches. Some module members favored this screening approach, while others questioned if such crude approximations were appropriate.

The resources required to conduct an analysis increase geometrically with the level of methodology. Level 1 methodology is a simple procedure to collect expert opinion and perform back-of-the-envelope analysis, without acquiring new field data. Level 2 methodology requires limited field studies and text book level analysis of the fate of pollutants such as heat, oxygen demand, solids, etc. Level 2 studies would require two to three man-months of effort. Level 3 methodologies are four to eighteen man-month efforts combining extensive field observations and mathematical modeling to predict time-dependent fluctuation in heat and chemical concentrations in a reach. Level 4 methodologies require extensive basic research to gain understanding of the fate of toxic pollutants and to define chronic exposure levels that impact the aquatic ecosystem. Level 4 methodologies seek to add to scientific understanding as the first priority, and will complicate rather than clarify most management decisions.

Level	Purpose	Cost (man-months)	Required Knowledge	Detail and Accuracy
1	Problem identification in river systems	1-2	General text book secondary data	Prioritize problems, screening, order of magnitude
2	Estimate flow in reaches	2-3	Nomographs, published methods, simple relationships, limited field trips	Select reaches for study, estimate habitat or recreational impacts. Better than factor of two.
3	Prepare data for legal or other action in policy arena--major confrontation aticipated - site specific	4-18	Intermediate level computer models, extensive field studies for calibration SOA	Best state-of-the-art values and complexity
4	Development of new methods and data advancing the SOA	unlimited	New research	Improvement of existing capabilities

TABLE 1

Framework for IFG Methodologies

Level	Purpose	Data Needs	Methods
1	Estimate if WQ (water quality) need by considered in IFG studies. Prioritize rivers in order of potential WQ problems.	Prior WQ studies or estimate of river mechanics and hydrology, land use, weather, etc. from past studies.	Nomographs, generalization from similar rivers.
2	Estimate reaches within rivers that will experience critical WQ problems at low flows.	• Low flow WQ data • Point and nonpoint source information • Level 2 hydrology and river mechanics data • Examination of pollutant levels in fish	Hand calculations, simple temperature/oxygen models. Estimate of toxicity problems.
3	Compute concentrations of oxygen, salts, temperature in reaches and impoundments. Estimate total loadings of critical toxicants or nutrients.	Level 3 hydrology and river mechanics data. Level 3 fish and recreation constraints. Extension of WQ data to calibrate temperature/oxygen computer models.	Existing water quality computer models for temperature, oxygen in streams and impoundments. Estimate toxic and trace pollutants near sources.
4	Develop detailed concentration in two dimensions, mixing zones of toxicant, pollutants. Combine ecosystem, flows, and WQ.	Extensive research on model development and data for model calibration.	IBP ecosystem-type models, multi-compartment, spatially disaggregational.

TABLE 2

IFG Water Quality Methodologies

TABLE 3. Hierarchial Levels of Analysis

LEVEL 1: SCREENING

1. Preliminary information collection: maps; reports; interviews.

2. Field inspection (1 man-day per 25 to 100 miles of stream).

3. Water quality sampling; one or two sets of diurnal DO and temperature data (2 men, 5 days).

LEVEL 2: LOW RESOLUTION

1. General layout of the stream system: USUS maps; gauging station records; reports; etc.

2. Field surveys (4 trips over 9-12 mo., 2 men 5 days each trip).

    a) Select representative (critical) reaches. Run transects.

    b) Develop V vs Q and d vs Q.

    c) Local morphology, substrate.

3. Historical flow records and proposed regulations.

4. Water quality grap samples (collected during field surveys).

LEVEL 3: MID RESOLUTION

1. Detailed layout of stream system. Steady flow water quality model.

2. Field surveys: (2 trips; 2 men 5 days each trip).

    a) Flow balance, headwater flow, lateral flow, point flow.

    b) Instream quality sampling: headwater; critical point.

    c) Point load sampling.

3. Biological sampling (2 trips; 2 men 5 days each trip).

LEVEL 4: HIGH RESOLUTION

1. Detailed layout of stream system. Ecological model with unsteady or steady flow and dynamic responses.

2. Field surveys: intensive physical and biological sampling with permanent stations and some continuous recordings.

The results of water quality model applications, therefore, must be carefully interpreted in the context of the ecological characteristics of the particular system and the intended beneficial uses of the water. So, in order to adequately evaluate a system, two types of information are necessary for each chemical form of potential significance:

1) Concentrations of the constituent in each of the major components of the ecosystem.

2) The significance to the beneficial use of the water of each form of the constituent in each part of the ecosystem.

The first type of information is usually provided by water quality models or field studies. Numerous satisfactory models are available for this purpose and the major problem is selecting the appropriate model resolution for a specific application. The second type of information is usually provided by "water quality standards" which specify maximum (or minimum) permissible levels of specific constituents. These standards are generally related to the beneficial use of the water body and are based on available information such as the U. S. Environmental Protection Agency water quality regulations of 1976.

The IFGIM utilizes fish behavioral preference curves to evaluate the significance of physical stream parameters on fish habitat. Unlike standards which delineate only two possibilities, acceptable or unacceptable, the IFGIM provides the relative effects of various flow alterations. Where data are available (i.e., temperature and oxygen) it may be possible to develop fish behavioral preference curves for water quality parameters. However, the consensus opinion of the module members was that the current IFGIM should not be extended to include multiplicative water quality weighting factors.

Summary

In summary, the water quality methodology should provide guidance for applying appropriate study intensity. In order to accomplish this, the methodology should include analytical techniques at several levels of resolution. The techniques should have state-of-the-art capabilities and should be directed toward the current needs of the IFG: predicting the effects of instream flow alterations to fish habitat.

The suggested methodology consists of four levels of resolution. It is proposed that the entire river system be evaluated using Level 1 techniques to determine which constituents pose a potential threat to fishery needs at altered flows. If water quality degradation potential is severe, the subsequent levels of analysis provide techniques for more price estimates of particular constituents at specific critical sites.

APPENDIX

Members of this module have attempted to provide examples of methodologies for each level of analysis. These examples are not comprehensive literature reviews or state-of-the-art presentations, but illustrations to indicate the type of analysis that could be obtained by increasing levels of investment. The key to optimizing the level of analysis required in the IFGIM is knowledge on the response of aquatic organisms to exposure of various pollutant concentrations. Since chronic exposure criterion need to be developed before such analyses are possible, the IFG will have to use Level 1 type analysis to establish such criterion before higher level water quality analysis can be justified.

LEVEL 1 ANALYSIS (BOGSAT)

Level 1 analysis consists of low-level reconnaissance and screening and may be characterized as BOGSAT: "A Bunch of Guys Sitting Around the Table." The first step in assessing water quality at this level is to identify point and non-point sources of waste. Much of this information has already been collected for many basins in conjunction with studies stimulated by P.L. 92-500 (i.e., 303e, 208, 316a, etc.) and state water quality regulations. The NPDES permits on file with EPA or state agencies provide useful information on point discharges. When measured data are not available, loadings may be estimated by standard factors such as these shown in Tables 4 and 5 for BOD and suspended solids or tables included in the Environmental Protection Agency's water quality regulations of 1978.

Fluctuation of water quality with inflows of waste is a significant factor in allocating waters for waste assimilation. In some cases return flows may contribute a majority of the downstream volume and management of return flow quality will become more important than management of upstream water quality.

Data may also be available on chemical concentrations as, for example, shown in Table 6 (Finney, et al, 1977). This type of data is useless unless accompanied by associated flows as shown in Tables 7 and 8 (Finney, et al, 1977). At this level of analysis, average loading rates and flows are used. Using the loading and hydraulic data, instream concentrations can be approximated by simple dilution calculations. Instream concentrations at alternate flows or for different loading patterns (i.e., future scenarios) can be estimated by the same technique.

The resulting water quality can be compared to instream standards,

TABLE 4. Population-Equivalent Conversion Factors for Industrial Wastes

Constituent in waste	Average Waste/capita lb/capita/day	Conversion Factor to PE per lbs of pollutant
Suspended Solids	.250	4
BOD (5 day, $20^{o}C$)	.166	6
Total Phosphorus	.009	110
Total Coliform	$1.6x10^{8}/100$ ml	-

TABLE 5. Population Equivalent Conversion Factors for Specific Industrial Wastes

Industry	Population Equivalent/ton of output			
	PE (BOD)		PE (Suspended Solids)	
	typical value	Range	typical value	Range
Food Processing	300	75-1200	180	6-300
Pulp & Paper - Kraft	700	240-2500	200	80-350
- Sulfite	4000	900-8000	200	80-350
Forest Product	$\leq$.1	-	3	-
Sand & Gravel	.4	.3-.6	800	-
Petroleum Refining	6	1-20	100	1-200
Light Mfg.	1/employee			

Source: Harper, M. S. and B. W. Mar
A Series of Methodologies for Estimating Low Flow Requirements Based on Water Quality Standards
State of Washington Water Research Center Report No. 13, June, 1973

TABLE 6. Chemical and Biological Characteristics of Selected River Systems

Description	Ortho-Phosphorus[a] (mg/l)	Ult. Biochemical Oxygen Demand[a] (mg/l)	Ammonia[a] (mg/l)	Nitrate[a] (mg/l)	Dissolved Oxygen[a] (mg/l)	Algae CHL "A"[b] (mg/l)
Headwater	0.1	3.0	0.0	0.3	13.5	0.06
Reaches 1-4, Lateral Surface Inflow	0.4	8.7	0.0	2.0	7.3	0.0
Reaches 1-4, Lateral Ground Inflow	0.0	0.1	0.0	1.9	0.0	0.0
Reaches 5-7, Lateral Surface Inflow	1.4	9.5	0.0	2.0	7.3	0.0
Reaches 5-7, Lateral Ground Inflow	0.0	0.1	0.0	2.1	0.0	0.0
Reaches 8-14, Lateral Surface Inflow	1.4	8.7[c]	0.0	2.0	7.6	0.0
Reaches 8-14, Lateral Ground Inflow	0.0	0.1	0.0	2.2	0.0	0.0
Sandy WTP	7.08	101.	22.1	0.19	3.95	0.0
Tri-Community WTP	8.84	74.5	15.7	1.13	3.95	0.0
Little Cottonwood Ck.	0.09	9.01	0.0	0.59	7.00	0.0
Murray WTP	7.45	83.2	13.4	4.45	3.95	0.0
Big Cottonwood Ck.	0.0	2.48	0.0	1.07	7.90	0.0
Cottonwood WTP	9.06	48.2	18.7	2.64	6.00	0.0
Granger WTP	11.2	88.8	5.62	0.91	6.00	0.0
Salt Lake Sub WTP	9.79	54.2	5.62	4.04	6.00	0.0
Mill Creek	0.01	2.10	0.0	1.98	7.90	0.0
South Salt Lake WTP	4.16	50.8	3.81	4.95	6.00	0.0
Parley, Emmigration and Red Butte Creeks	0.05	4.20	0.0	1.26	7.00	0.0
City Creek	0.09	1.67	0.0	1.51	7.90	0.0
South Davis WTP	5.19	47.7	13.7	1.92	3.95	0.0

[a]Source: Salt Lake County Council of Governments (1977a)
[b]Source: Dixon, et al. (1975)
[c]For reach 13 = 148 mg/l (Bowles, 1977)

TABLE 7. Headwaters, Point Loads, Diversions and Surveillance Points

Description	Location (miles)[a]	Flow (f^3/sec)[b]
Jordan River headwater	40.8	15.0
Galenda Canal	37.2	-8.0
Beckstead Ditch	34.2	-4.0
North Jordan Canal	30.0	-96.0
Sandy WTP (ℓ= 1)	28.9	5.0
Tri-Community WTP (ℓ = 2)	26.5	10.0
Surveillance Point (k = 1)	26.0	
Little Cottonwood Ck	22.8	10.0
Brighton Canal	22.2	-30.0
Murray WTP (ℓ = 3)	22.0	6.0
Big Cottonwood Ck	21.4	45.0
Cottonwood WTP (ℓ = 4)	21.4	13.0
Granger Hunter WTP (ℓ = 5)	18.7	12.0
Salt Lake Sub WTP (ℓ = 6)	18.3	21.0
Surveillance Point (k = 2)	18.1	
Milk Ck	18.1	15.0
Surplus Canal	16.7	-225.0
South Salt Lake WTP (ℓ = 7)	16.2	7.0
Parley, Emmigration and Red Butte Cks.	15.0	18.0
City Ck.	12.4	6.0
Surveillance Point (k = 3)	12.0	
South Davis WTP	5.9	3.0

[a]1 mile = 1.61 km

[b]1 ft^3/sec = 1.70 m^3/min

Source: Bowles (1977)

TABLE 8. Physical Characteristics of River Reaches

Reach	Location (miles)[c]	Lateral[a] Surface Flow (ft^3/sec/mile)[d]	Lateral[a] Ground Flow (ft^3/sec/mile)[d]	Velocity[b] Coef. Θ_1	Velocity[b] Exp. Θ_2	Hydraulic[b] Rad. Coef. Θ_3	Hydraulic[b] Rad. Exp. Θ_4	Temperature (°C)[e]
1	40.8	8.0	3.0	.310	.120	.206	.568	20
2	36.0	8.0	3.0	.310	.150	.201	.588	20
3	34.2	8.0	3.0	.310	.150	.201	.568	20
4	32.1	8.6	3.0	.310	.140	.202	.581	20
5	30.0	11.0	18.0	.300	.333	.031	.792	20
6	27.9	11.0	18.0	.520	.345	.058	.766	20
7	26.5	11.0	18.0	.450	.347	.053	.795	20
8	25.0	6.0	6.0	.450	.347	.053	.795	20
9	22.8	6.0	6.0	.740	.228	.235	.400	20
10	21.4	6.0	6.0	.400	.301	.109	.688	20
11	18.1	6.0	6.0	.157	.384	.021	.843	20
12	16.7	1.0	0.1	.009	1.000	2.200	0.0	20
13	15.0	1.0	0.0	.009	1.000	2.200	0.0	20
14	12.0	1.0	0.0	.009	1.000	2.200	0.0	20

[a]Source: Salt Lake County Council of Governments (1977a)

[b]Source: Salt Lake County Council of Governments (1977a) (Reaches 1-4), Dixon, et al. (1975) (Reaches 5-11), Salt Lake County Council of Governments (1977a) (Reaches 12-14)

[c]1 mile = 1.61 km

[d]1 ft^3/sec/mile = 1.056 m^3/min/km

[e] $^{o}C = \frac{5\ (^{o}F - 32)}{9}$

for example, the U.S. Environmental Protection Agency's water quality regulations of 1976, to estimate potential problem constituents and critical reaches. Since it is difficult to obtain adequate information on atmospheric conditions, channel characteristics, and sources of wastes to predict natural water quality closely, the impact of flow alterations can be simplified if baseline water quality data are available.

Because the initial focus of the water quality effort will be directed toward fish habitat, dissolved oxygen (DO) and temperature will be the most important constituents for most reaches. A worst case estimate of DO in a river with significant BOD content is achieved when it is assumed that the oxygen deficit equals the ultimate BOD concentration. The ultimate BOD concentration would be estimated as the total BOD loading dissolved in the average river low flows. If this estimate is near acceptable levels for fish of interest, then a Level 2 analysis should be conducted. If oxygen levels estimated by this method are above acceptable limits, the assumption that oxygen will not be limiting might be made.

Water temperature can be estimated at Level 1, knowing latitude, altitude, river depth, velocity at representative reaches, the time of year, and the canopy of the river. If the river is completely shaded for its entire length, temperature will not change as flows are decreased as much as in an unshaded river. If the river is completely exposed to the sun, and average cloud cover is small, then flow changes can impact temperature. Water temperature can be estimated at Level 1 by generalization from similar conditions in nearby rivers or simplified heat balances for a representative water column.

As a first approximation water temperature changes are assumed to increase proportionately with travel time and inversely with the mean depth. Water exposed for a long time to a given set of meteorological conditions will reach an "equilibrium temperature" (Edinger and Geyer, 1968). For example, the equilibrium water temperature can provide an estimate of average temperature condition. An average equilibrium water temperature, $\bar{T}_e$, can be calculated using average daily meteorological conditions. By comparing the average daily observed water temperature, $\bar{T}_o$ to $\bar{T}_e$, the following inference can be made:

1) If $\bar{T}_o = \bar{T}_e$; temperature is not sensitive to flow.

2) If $\bar{T}_o < \bar{T}_e$; temperature may increase with reduced flow.

3) If $\bar{T}_o > \bar{T}_e$; temperature may decrease with reduced flow.

Novotny and Krenkel (1973) have observed that an initial temperature increase in a stream is dissipated exponentially with time until the original or natural temperature region is reached and that in some cases "equilibrium temperatures" are not required to estimate thermal discharge impacts.

Up to this point only average loadings, flows, and instream concentration have been considered. The temperature or oxygen content of most rivers and estuaries cannot be characterized by a single observation taken at a given time of day or place. Diurnal fluctuations can be as great as $\pm$ 10°F and $\pm$6 ppm of oxygen in a river as large as the Willamette (Hines, 1977). Figure 1 presents data for oxygen and temperature for flows of about 5000 cfs reported by Hines. Thus natural flows may have major temperature and oxygen fluctuations that can be aggravated by reduced flows.

If data are not available for a diurnal cycle of DO and temperature, then at least one field trip should be made to collect the data during low flow conditions. The observed diurnal fluctuation can be superimposed on the average to obtain a first approximation of maximum and minimum concentrations at other flow conditions.

Data on concentration-duration of exposure relationship that are detrimental to aquatic organisms are lacking, and should be the thrust of scientific research to estimate the impact of water quality changes of beneficial uses that are related to aquatic organisms.

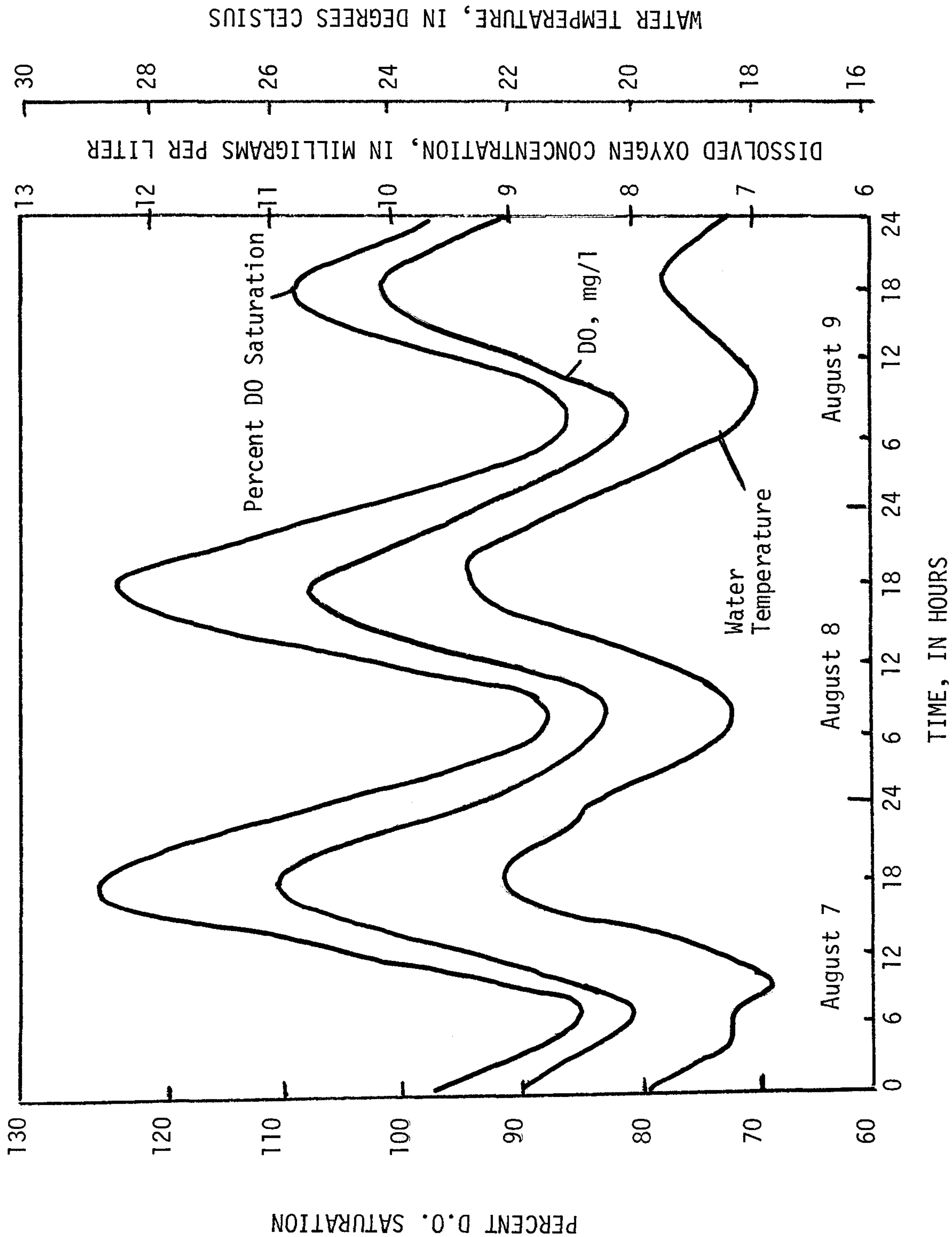
WATER TEMPERATURE, IN DEGREES CELSIUS
DISSOLVED OXYGEN CONCENTRATION, IN MILLIGRAMS PER LITER
PERCENT D.O. SATURATION
TIME, IN HOURS
Percent DO Saturation
DO, mg/l
Water Temperature
August 7
August 8
August 9

FIGURE 1.

LEVEL 2 ANALYSIS (BOGSAR)

The goal of Level 2 is to further evaluate reaches where the effects of water quality must be included in the evaluation of habitat and may be characterized as BOGSAR: "A Bunch of Guys Standing Around the River." Table 9 includes examples of Level 2 analyses.

Level 2 water quality assessment is based on field observation of water quality at extreme-flow conditions (high and low flows) and at known waste discharge locations. Knowledge of BOD and temperature at these conditions will provide data for nomographs or hand calculations of elementary first order data equations used in oxygen estimations.

Inputs from the IFG Incremental Methodology will provide depth and velocity to greater detail than this methodology requires. Fishery and recreation studies (Levels 1 and 2) should define acceptable water quality conditions, as well as a forecast of human activity and land use that can be used to estimate pollution loads. General data such as weather, aerial photographs, soil maps, etc. can provide information on canopy and solar inputs for temperature calculations using nomographs and generalized data from existing studies and models.

While methodologies to model other pollutants are not found in common texts on water quality, there are water quality criteria available for many other pollutants than temperature and oxygen. The Level 2 analysis should survey water samples and the flesh of fish for the presence of as many pollutants as resources permit.

Prediction of Water Temperature

Conceptually, water temperature models have not changed significantly from the energy balance employed by Raphael (1962). Recent temperature

TABLE 9. Level 2 Analysis

I. TOTAL DISSOLVED SOLIDS (TDS)

A. No sources greater than 2000 mg/l TDS.

B. Calculate dilution factor; no instream concentrations greater than 2000 mg/l TDS.

C. No significant increase in instream concentration from headwater to downstream section.

II. DISSOLVED OXYGEN (DO)

A. Instream DO greater than 6.0 mg/l at sunrise.

B. Instream BOD less than 5.0 mg/l near discharges.

C. Instream NH_4-N less than 1.0 mg/l near discharges.

III. SUSPENDED SOLIDS (SS)

A. Absence of sludge banks downstream from discharges.

B. SS less than 10 mg/l

C. U.S. Forest Service Stream Reach Inventory and channel stability evaluation less than 38.

IV. TEMPERATURE (Temp.)

A. Compare instream temperatures at sunrise and 3:00 p.m. to critical values for indigenous species.

B. Compare headwater temperatures to downstream temperatures.

C. Equilibrium temperature analysis.

1. Calculate equilibrium temperature (ave. daily meteorological conditions), $\overline{Te}$.
2. Calculate ave. daily observed temp., $\overline{To}$
3. If $\overline{To} \simeq \overline{Te}$; Temp. not sensitive to flow.
4. If $\overline{To} < \overline{Te}$; Temp. may increase significantly with reduced flows.
5. If $\overline{To} > \overline{Te}$; increased flow may significantly decrease temperature.

V. TOXICITY

1. Instream pH greater than 6.5
2. Calculate index, I, (Sparks, 1977):

$$I = \frac{\text{unionized ammonia (N mg/l)}}{(1.9)\,[0.0133(\%\text{ DO saturation})-0.330] \text{ or } [0.02]}$$

$$+ \frac{[\text{Total arsenic (as mg/l)}]}{20.2}$$

$$+ \frac{[\text{Total boron (B mg/l)}]}{2393}$$

$$+ \frac{[\text{Total cadmium (Cd mg/l)}]}{0.100321\,(\text{hardness})-0.066417}$$

$$+ \frac{[\text{Total hexavalent chromium (Cr mg/l)}]}{125.5}$$

$$+ \frac{[\text{Total copper (Cu mg/l)}]}{[0.0318(\text{hardness})-0.248]\,[0.722 \log(\%\text{ DO sat.}-0.437)]}$$

$$+ \frac{[\text{Total cyanide (Cn mg/l)}]}{[0.235-0.00333(\text{Temp})]\,[0.00309(\%\text{DO sat.})-0.691]}$$

$$+ f(\text{Fe, LAS, Pb, Mn, Hg, Ni, } NO_3\text{, phenol, Ag, Zn})$$

3. If $I \geq 1$; go to next level.

models (Novotny and Krenkel, 1973; Brocard and Hardemann, 1976; DeWalle; 1976) continue to employ an energy balance of net solar radiation input and surface gains or losses by evaporation (condensation), convection, and back radiation. The advection of water at different temperatures than that of the main stream is computed by mixing models and heat losses to the channel bottom are usually neglected. More complex models do not assume perfect mixing and no heat loss to the channel. These complex models predict thermal stratification and two or three-dimensional temperature distributions in the waters.

Unless extensive atmospheric data and flow data are available, temperature models cannot be calibrated for a specific reach. Electric utilities and regulatory agencies responsible for protection of aquatic life forms from thermal pollution have invested in the development of complex models for predicting water temperature (Hill and Viskanta, 1976). The task for this workshop is to extract from this rich literature an effective and simple methodology to estimate water temperature changes associated with flow reduction, given local meteorological conditions.

If a body of water of uniform depth is exposed to a sequence of warming days with identical pattern of diurnal meteorological conditions and is continually well mixed, the water temperature will follow a trend shown in Figure 1. As observed by Novotny and Krenkel (1973), no matter what the initial water temperature may be, the water temperature will seek an "equilibrium pattern." Since there are many computer models that can evaluate the water temperature given sequences of meteorological conditions, it would be possible to prepare charts of water temperature from sequence of meteorological condition and canopy cover as a function of flow time and river depth if the initial water temperature is given. While such calculations would ignore the change of geometry in a natural channel and tributary inflows, it would provide a simple set of figures to estimate impacts of flow changes. Two alternative methodologies are proposed to develop such data as shown in Figure 1.

Method 1

A change in temperature of a column of well-mixed water of depth d is:

$$\Delta T_w = \frac{Qt\ \Theta}{62.4\ d} \qquad \text{(assuming no condition of water)}$$

where Q_t = net heat transfer across water surface averaged over the computational period Btu/sqft/hr (cal/cm^2/hr)

Θ = time of exposure to Q_t, hrs

d = depth of water column Δ/v (area surface/volume)

The net heat transfer obtained by an energy budget (Raphael, 1962)

$$Q_t = Q_{net} - Q_b + Q_n - Q_e$$

$Q_{net} = (1 - .17\ C^2)(Q_s - Q_r)$ = net shortwave radiation

Q_s = incoming solar radiation

Q_r = reflected solar radiation

C = cloud cover in tenths

$Q_b = 0.97\gamma\ (T_w^4 - \beta T_a^4)$ back radiation

$Q_e = 12\ U(e_w - e_a)$ evaporation

$Q_n = 0.004\ UP(T_a - T_w)$ conduction

where T_w = water temperature

T_a = air temperature

e_w = vapor pressure of air at water surface temperature

e_a = vapor pressure of air

U = wind speed

P = atmospheric pressure

A computer can easily process these equations and estimate water temperature as a function of time, given a set of meteorological data.

Method 2

Since the change in water temperature due to flow reduction is only a function of water temperature and water depth (all other parameters are atmospheric conditions), these equations can be rewritten.

$$\Delta T_w = \frac{Q_t(T_w)}{d} K_1$$

where $K_1 = \frac{\Theta}{62.4} = \text{constant}$

and

$$Q_t(T_w) = K_2 + K_3(T_w)$$

where $K_2 = Q_{net} - \beta .97\sigma T_a^4 - 12Ue_a + .004\ UPT_a$

and

$$K_3(T_w) = \alpha T_w^4 - \gamma(T_w)$$

$$\alpha = .970$$

$$\gamma = 12UW - .004UP$$

As an alternative to a computer program for analysis of the heat balance, a computer program can be developed to compute $Q_t(T_w)$ as a function of T_w as shown in Figure 2. A stepwise estimation of water temperature can be made using such curves by using the initial water temperature as a starting point and observing the corresponding $Q_t(T_w)$ for the net times increment and then computing the water temperature change in the water of depth d. Repeating this process for a set of depths will provide an

	Q_{net}	T_a(°F)	U	e_a
0-3am	0	53	8	.36
3-6	0	54	6	.33
6-9	80	61	9	.35
9-12	260	74	9	.34
12-3	250	83	10	.39
3-6	150	87	12	.31
6-9	20	80	9	.39
9-12	0	64	8	.41

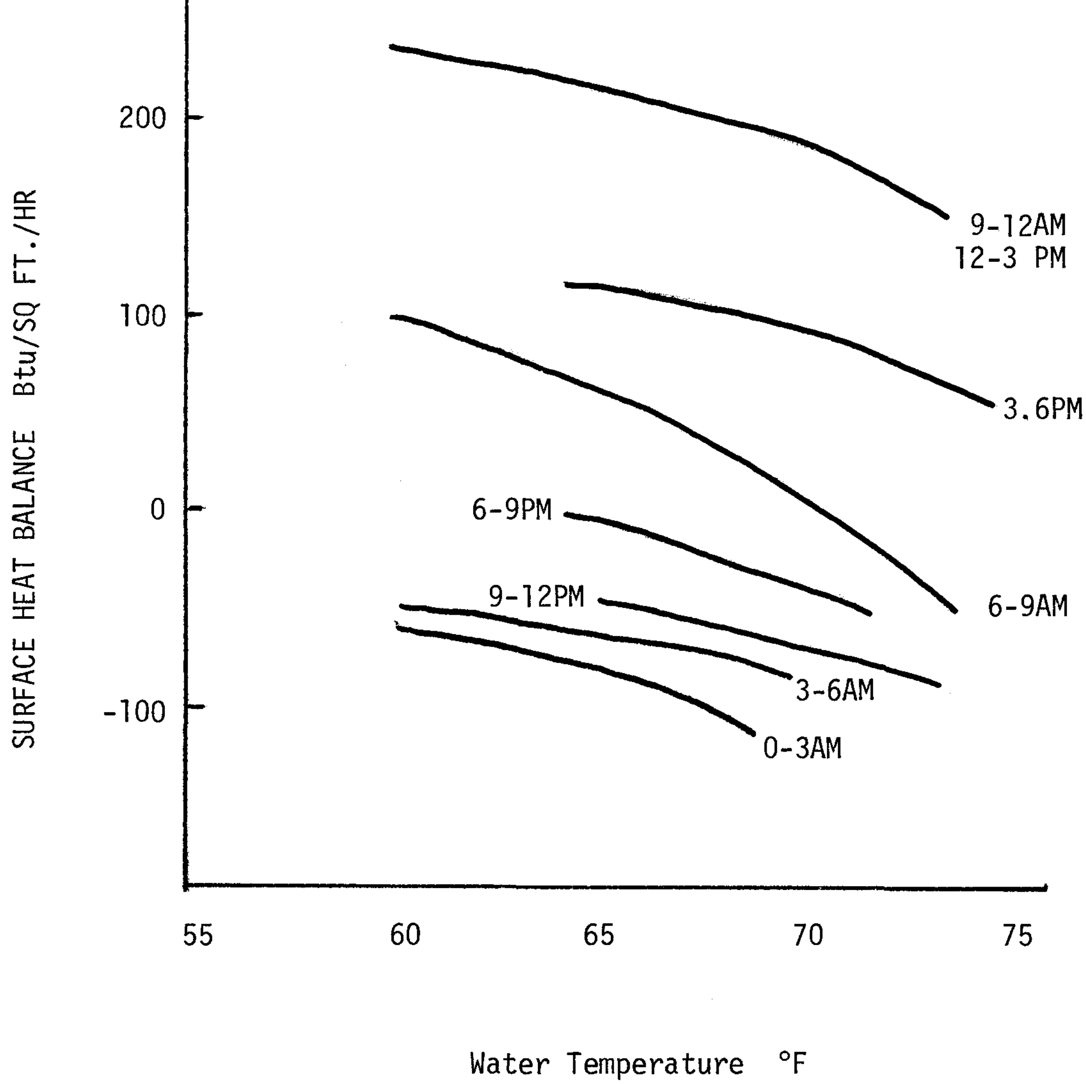

FIGURE 2. WATER SURFACE HEAT BALANCE AS A FUNCTION OF WATER TEMPERATURE.

alternative method to generate curves as shown in Figure 1 for any given set of diurnal atmospheric conditions.

The impact of flow reduction on temperature can be estimated by selecting a sequence of meteorological conditions (either hourly or three hourly) and computing the natural variation in water temperature for the existing water depth and travel time. Knowing the reduction in water depth or the increase in travel time, the new water temperature can be obtained from curves as shown in Figure 2. For example, if existing conditions in a reach were a depth of six feet and a travel time of 48 hours, the temperature region would be estimated as 65°-68°F. If flow changes resulted in depths of three feet and flow times of 96 hours, the temperature region would be estimated as 68°-72°F from Figure 2.

Since the flow can be stated as a probabilistic distribution of depth and velocity, these can in turn be used with the water temperature curves to develop a statement of anticipated water temperatures. The weakest link in this methodology will be the selection of meteorological conditions. DeWalle (1976) has shown that errors of several degrees Fahrenheit are commonly associated with normal inaccuracies in wind and vapor pressure.

Prediction of Other Pollutants

There are many other constituents in the waters of streams, lakes, and estuaries that impact fish and wildlife. Some constituents such as oxygen content, acids, bases, and salts are of concern when levels are high enough to stress fish and cause illness or death. Other constituents which in high enough concentration are lethal are concentrated in fish even when concentrations in the water are non-lethal. These constituents such as pesticides and PCB's are of concern since they can contaminate food fish and higher food chain members, including man.

The key to the Level 2 approximation of reduced flow impacts on the concentration of any pollutant is to have knowledge of the existing concentrations of these pollutants in the waters of interest. Unless sources of these pollutants are known or can be estimated, and the data are available for ambient concentration of these pollutants in the receiving waters, there is little basis for prediction of water quality changes associated with flow reduction. The first step in developing an incremental approach to water quality impacts of low flows will be to establish the minimum set of base line pollutant source and water quality data necessary to support such efforts.

While a simple dilution model is unacceptable to most individuals knowledgeable in water quality predictions, the dilution model may be a possible method to classify the magnitude of concern that should be given to particular low flow reduction proposals. Once the priority of the problem can be estimated, the level of analysis can be defined. The classical equation for waste oxidation and stream reaeration can be modified by simple first order rates for benthic demands or contributions. Since algae contributes significantly to oxygen during daylight periods, more complex aquatic ecosystem models may become necessary if the waters are eutrophic. Grenney, et al. (1976) have presented existing model capabilities and Hines (1977) has shown how such models can be applied to actual management decision.

The IFG may not need to duplicate such studies, since most agencies involved in control of water wastes employ such models. If an appreciation of the sensitivity of such models to changes in depth, velocity, and temperature can be developed, this may be adequate for instream flow analysis. Models should be used to generate a base line condition, and then response to alternative flows (with associated depths, velocities, and temperatures) evaluated. Curves showing the variation in pollution as a function of river mile will be developed for various flows.

As was discussed earlier, the knowledge of sources of oxygen-demanding waste is a critical input for such calculations. The other major factor in prediction of pollutants that react with the food web are appropriate rate constants for various reactions in each trophic level. Since these constants must be used by all parties in the evaluation of water quality, it is suggested that the IFG use constants that have been defined in the literature for "first cut" analyses.

Many pollutants have been related to sediment loads and simple models relate concentration of pollutant in water to a multiplier times sediment loads. This suggests that low flow periods may not be the critical periods for pollutants since sediment loads increase with flow. If sediment loads are reduced as a product of instream flow management, there may be a related lowering of concentration of pollutants associated with sediment. The interface between the water quality module and the sediment transport module must be another future task for the IFG if water models are to be improved.

A simplified model for phosphorus mass balance in lakes has been suggested by Vollenweider (1975, 1976) and Dillion and Rigler (1974). They assume lakes can be approximated as a completely mix flow-through reactor with constant influx of phosphorus and that phosphorus losses occur through the outflow and sedimentation. The model expresses the steady state phosphorus concentration in the lake (P) as

$$P = Po \frac{\rho}{\sigma + \rho}$$

where Po = the inflow concentration of phosphorus

ρ = flushing rate = annual inflow/lake volume

σ = sedimentation rate

Vollenweider (1975) suggests that the sedimentation rate can be expressed as

$$\sigma = \frac{10}{\bar{Z}}$$

where $\bar{Z}$ = mean lake depth in meters,

and in 1976 revised this to

$$\sigma = \sqrt{\rho}$$

thus

$$P = Po \frac{\rho}{\rho + \sqrt{\rho}}$$

If the reduced flows contain the same or lower concentrations of phosphorus, then the total annual phosphorus load will be reduced. Uttormark (1978) shows that the

$$\frac{\underline{P'}}{\underline{\underline{P}}} = \left[1 + \frac{\rho 2}{\rho 1} \frac{\underline{Po_2}}{\underline{Po_1}}\right] \left[\frac{\rho_1 + \sqrt{\rho 1}}{\rho_1 + \rho_2 + \sqrt{\rho_1 \; \rho_2}}\right]$$

where Po_2 is the concentration of the flushing or withdrawn water and Po is the concentration of inflow prior to aeration.

$P_1 = \frac{Q}{V}$ before addition

$P_2 = \frac{Q_2}{V_2}$ the amount added

This simple mixed reaction, first order removal model may be useful to estimate the fate of other nutrients or materials that are assimilated by the food web.

Thomann (1978) suggests that the concentration in any trophic level in the food chain can be related to the water concentration by a proportionality constant that is a function of the organism length and uptake, excretion, respiration, and transfer coefficients.

LEVEL 3 SOA (STATE-OF-THE-ART)

Methodologies are available to estimate hourly values of oxygen in a river to ± 1 ppm and water temperature with $\pm 1°F$ if adequate information is known for boundary conditions, BOD loadings and atmospheric conditions, and river mechanics. Grenney, et al. (1976) have presented a comprehensive review of SOA methodologies of such water quality models. While the number of publications on water quality models has been significant since 1976, there have been few significant advances in the fundamental theories.[1] The major thrusts of recent water quality modeling efforts are concerned with the improvement of constants or parameters included in the models, the development of analytical or numerical techniques to increase computational efficiencies, or the application of models to specific locations. Tetra Tech, Inc. (1978) has developed a manual of constants for use in water quality models funded by EPA. It contains a review of recent data used in water quality models. Models at this level generally include some additional level of detail and interactions and, given the present state-of-the-art, are focused on temperature and diminished oxygen. The components of the field work and necessary components for the model are listed below. It should be stressed that not all river problem settings will require all components, and judgment and experiences are necessary to proscribe model boundaries and complexity.

It is also assured at this Level 3 that Levels 1 and 2 have also been essentially completed, i.e., that initial reconnaissance, problem specification and screening have been accomplished. Following the

[1]The Journal of the Water Pollution Control Federation publishes in June of each year an annual literature review that includes advances in water quality models.

preliminary steps, the elements listed below would form a "typical" field program. The completion of the analysis would generally include:

a) compilation and analysis of the field data

b) access to computer program of DO and temperature

c) calibration of data to model one survey set

d) verification of other survey sets to obtain a consistent set of coordinates

e) projection of input loads and flow regimes

f) simulation of water quality response using verified model

The detailed model specifications are summarized in Table 10, which summarizes the resolution of models at Level 3. Tables 11 and 12 present the basic equations and variables that are used in these models.

TABLE 10. Level 3 Model Resolution

FLOW: Steady first-order, nonuniform low flow conditions

PARAMETERS IN THE MODEL:

Dissolved Oxygen	(diurnal variation)
Temperature	(diurnal variation)
BOD	(steady-state)
Ammonia	(steady-state)
Nitrite-Nitrate	(steady-state)
Organic nitrogen	(steady-state)

BOUNDARY COLIFORM CONDITIONS:

Headwaters: Observed variable for DO and Temp.
Constant in time for others.
Point loads: Constant with time.
Kinetic coefficients: Constant with time.
Nonpoint loads: Constant with time (benthic).

FIELD MEASUREMENTS (Diurnal)

1) Instream Flows - Sufficient data to calculate velocity and depth as a function of flow.

BOD_u

NH_3, NO_2 and NO_3, TKN

D.O.

Benthic demand

Light penetration (Secchi depth)

Turbidity

Solids (Total, volatile, suspended)

(P and R)

Temperature

pH

2) Loads

Point: BOD, DO, NH_3, NO_2 & NO_3, flows, temp., pH

Nonpoint including benthic

OUTPUT

1. Typical (critical) diurnal variations in DO and temperature along the stream for various flow rates and upstream loading patterns.

LEVEL OF EFFORT

Four to six man-months

Level 3 TDS, D.O.

STREAM SIMULATION AND ASSESSMENT MODEL (SSAM)

HYDRAULICS: Steady, nonuniform flow

$$Q_x = Q_o \pm q_s \Delta X \pm q_g \Delta X - EW \Delta X + q_p - q_d$$

I. Parameters (constant with time)

Q_x	:	flow at downstream end of reach	(m^3/min)
Q_o	:	flow at upstream end of reach	(m^3/min)
q_s	:	lateral surface inflow (outflow)	(m^3/min·m)
q_g	:	lateral groundwater inflow (outflow)	(m^3/min·m)
E	:	evaporation in reservoir reach	(m^3/min·m^2)
q_p	:	point load	(m^3/min)
q_d	:	point diversion	(m^3/min)
ΔX	:	reach length	(m)
W	:	stream width	(m)

II. Internal hydraulic calculations

$$\bar{A} = a\ Q^{b1}$$

$$R = a\ Q^{b2}$$

III. Size: any reasonable number of headwaters, tributaries, point loads and diversions.

WATER QUALITY: One-dimensional, steady state, no dispersion.

$$C_i = \pm \frac{L_i}{\bar{R}} + \frac{q_s(C_{si} - C_i)}{\bar{A}} + \frac{q_g(C_{gi} - C_i)}{\bar{A}} + f(C_i, x)$$

I. Parameters (constant with time)

C_i	:	concentration of constituent i	(mg/l)
L_i	:	benthic load	$(g/m^2 \cdot min)$
C_{si}	:	concentration in lateral surface flow	(mg/l)
C_{gi}	:	concentration in lateral groundwater	(mg/l)

II. Water quality constituents

TDS	:	conservative
Coliform	:	(temp); first-order decay
BOD	:	(temp, algae); first-order oxidation
Ammonia	:	(temp, BOD, algae); first-order nitrification
Nitrate	:	(ammonia)
Phosphorus	:	(algae); first-order removal
Algae	:	(ammonia, nitrate, phosphorus, temp); monod kinetics
D.O.	:	(ammonia, algae, BOD, temp, elev $\bar{u}$, $\bar{r}$)

Level 3 Temperature

HYDRAULICS: Steady, nonuniform flow

(same as SSAM)

TEMPERATURE: One-dimensional, dynamic, no dispersion

$$\mathring{T} = \frac{Q_t}{c\rho h} + \frac{q_s(T_s - T)}{c\rho \bar{A}} + \frac{q_g(T_g - T)}{c\rho \bar{A}}$$

$$Q_t = Q_{net} - Q_b + Q_n - Q_e$$

I. Time constant parameters:

T_s	:	temperature of lateral surface inflow
T_g	:	temperature of lateral groundwater inflow

T_p	:	temperature of point loads
T_h	:	temperature of headwaters
c	:	specific heat of water
ρ	:	density of water

II. Time variable parameters:

Q_{net}	:	net shortwave radiation
Q_b	:	(T, T_a) back radiation
T_a	:	air temperature
Q_e	:	(V_w, e_w, e_a) evaporation
e_a, e_w	:	vapor pressures
Q_n	:	(V_w, P, T_a, T) conduction
P	:	atmospheric pressure

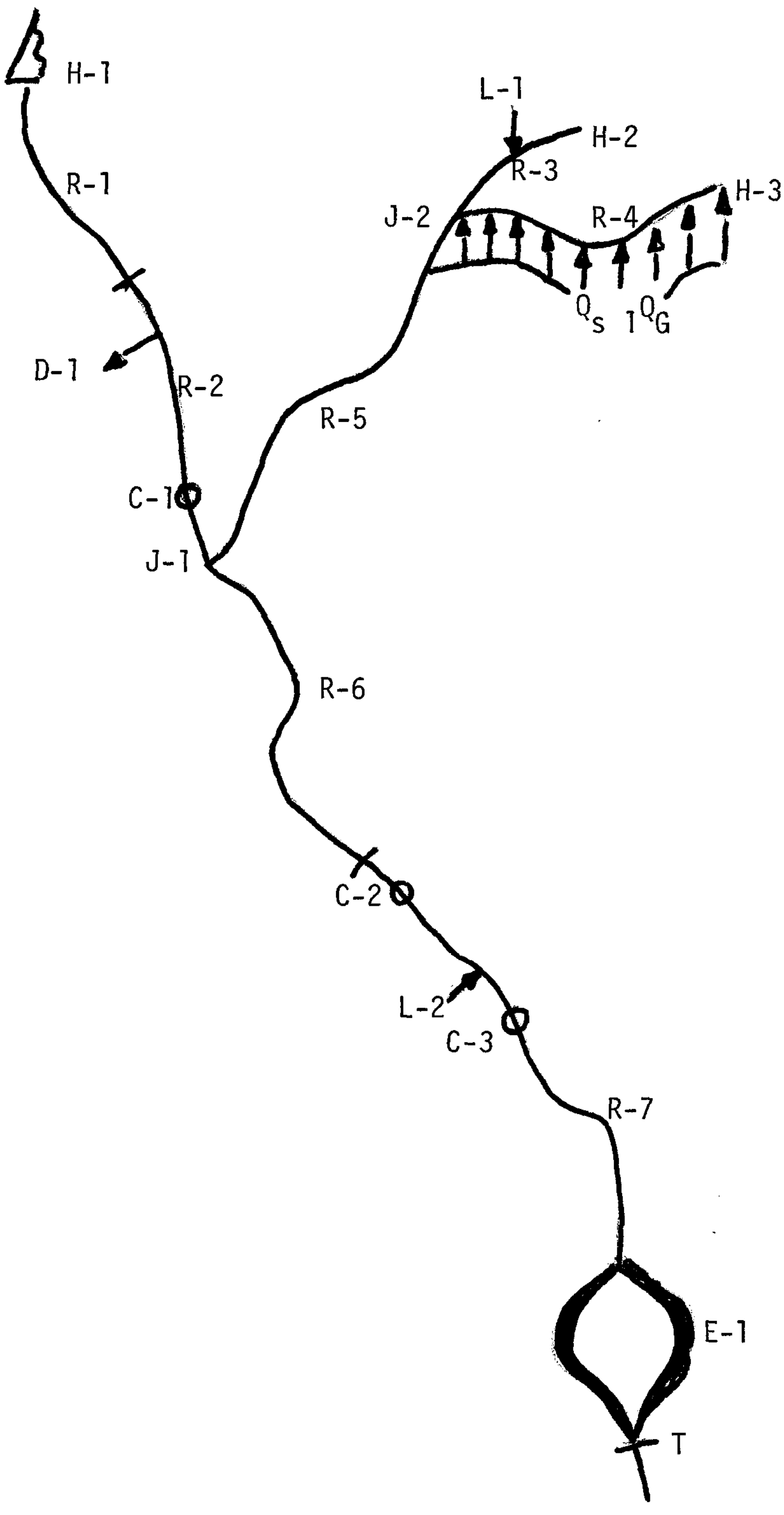

FIGURE 2-1. EXAMPLE OF A RIVER SYSTEM LAYOUT FOR THE WATER QUALITY SIMULATION MODEL.

TABLE 11. Equations used in exact and numeric solution model.

Description	CODE	ICODE	Equation
Nonconservative Exact and Numeric	NC01	1	$\dot{X}_1 = -\beta_{1,1}X_1 + S_1$
Nonconservative Exact and Numeric	NC02	2	$\dot{X}_2 = -\beta_{2,1}X_2 + S_2$
Nonconservative Exact and Numeric	NC03	3	$\dot{X}_3 = -\beta_{3,1}X_3 + \beta_{3,2}\beta_{2,1}X_2 + S_3$
Nonconservative Exact and Numeric	NC04	4	$\dot{X}_4 = -\beta_{4,1}X_4 + \beta_{4,2}\beta_{2,1}X_2 + \beta_{4,3}\beta_{3,1}X_3 + S_4$
Coliform Exact and Numeric	COLI	5	$\dot{X}_5 = -\beta_{5\ 1}X_5 + S_5$
Phosphorus Exact	PHOS	6	$\dot{X}_6 = -\beta_{6,1}X_6 + S_6$
Numeric			$\dot{X}_6 = -\beta_{6\ 1}X_6 - \beta_{6\ 2}\mu X_{12} + S_7$
Biochemical Oxygen Demand Exact	CBOD	7	$\dot{X}_7 = -\beta_{7,1}X_7 - \beta_{7,2}X_7 + S_7$
Numeric			$\dot{X}_7 = -\beta_{7,1}X_7 - \beta_{7,2}X_7 + \beta_{7,3}\beta_{12,2}X_{12} + S_7$
Ammonia Exact	NH3N	8	$\dot{X}_8 = -\beta_{8,1}X_8 - \beta_{8,2}X_8 + \beta_{8,3}\beta_{7,1}X_7 + S_8$
Numeric			$\dot{X}_8 = -\beta_{8,1}X_8 - \beta_{8,2}X_8 + \beta_{8,3}\beta_{7,1}X_7 - \beta_{8,4}\left(\frac{\beta_{8,5}X_8}{\beta_{8,5}X_8 + X_9}\right)\mu X_{12} + S_8$

TABLE 11. Continued.

Description	CODE	ICODE	Equation
Nitrate	NO3N	9	
Exact			$\dot{X}_9 = -\beta_{9,1}X_9 + \beta_{8,1}X_8 + S_9$
Numeric			$\dot{X}_9 = -\beta_{9,1}X_9 + \beta_{8,1}X_8 - \beta_{9,2}\left(1 - \frac{\beta_{8,5}}{\beta_{8,5}X_8 + X_9}\right)\mu X_{12} + S_9$
Dissolved Oxygen	DOXY	10	
Exact			$\dot{X}_{10} = \beta_{10,1}(\beta_{10,2} - X_{10}) - \beta_{7,1}X_7 + \beta_{10,3} - 4.33\beta_{8,1}X_8 - \beta_{10,4}X_{10}/\bar{R} + S_{10}$
Numeric			$\dot{X}_{10} = \beta_{10,1}(\beta_{10,2} - X_{10}) - \beta_{7,1}X_7 + \beta_{10,3} - 4.33\beta_{8,1}X_8 - \beta_{10,4}X_{10}/\bar{R} + \beta_{10,5}X_{12} + S_{10}$
Temperature	TEMP	11	
Exact and Numeric			$\dot{X}_{11} = \beta_{11,1}(\beta_{11,2} - X_{11}) + S_{11}$
Algae	ALGP	12	
Numeric			$\dot{X}_{12} = \mu X_{12} - \beta_{12,2}X_{12} + S_{12}$

NOTE: $\dot{X}_i$ represents the time derivative of the variable

$S_i = L_i/\bar{R} + (S_{si} + S_{Gi})/\bar{A}$

$$\mu = \beta_{12,1}\left(\frac{X_6}{\beta_{6,3} + X_6}\right)\left(\frac{\beta_{9,3}X_8 + \beta_{8,6}X_9}{\beta_{9,3}\beta_{8,6} + \beta_{9,3}X_8 + \beta_{8,6}X_9}\right)$$

$S_{si} = \begin{cases} Q_s\,(X_{si} - X_i) & \text{(flow into reach; } Q_s \text{ positive)} \\ 0 & \text{(flow out of reach; } Q_s \text{ negative)} \end{cases}$

$S_{Gi} = \begin{cases} Q_G\,(X_{Gi} - X_i) & \text{(flow into reach; } Q_G \text{ positive)} \\ 0 & \text{(flow out of reach; } Q_G \text{ netative)} \end{cases}$

TABLE 12. Definition of Model Coefficients Grouped by Water Quality Parameter

Parameter	Coefficient		Description	Coefficient Needed for	
	Symbol	Units		Exact	Numeric
NCO1	$\beta_{1,1}$	per day	First order decay rate	X	X
NCO2	$\beta_{2,1}$	per day	First order decay rate	X	X
NCO3	$\beta_{3,1}$	per day	First order decay rate	X	X
	$\beta_{3,2}$	mg NCO3/mg NCO2	Stoichiometric ratio	X	X
NCO4	$\beta_{4,1}$	per day	First order decay rate	X	X
	$\beta_{4,2}$	mg NCO4/mg NCO2	Stoichiometric ratio	X	X
	$\beta_{4,3}$	mg NCO4/mg NCO3	Stoichiometric ratio	X	X
COLI	$\beta_{5,1}$	per day	First order decay rate	X	X
PHOS	$\beta_{6,1}$	per day	First order removal rate	X	X
	$\beta_{6,2}$	mg PHOS/mg ALGP	Yield coefficient		X
	$\beta_{6,3}$	mg/l	Half saturation coefficient		X
CBOD	$\beta_{7,1}$	per day	First order oxidation rate	X	X
	$\beta_{7,2}$	per day	First order removal rate	X	X
	$\beta_{7,3}$	mg CBOD/mg dead ALGP	Ratio of CBOD to dead ALGP		X

TABLE 12. Continued.

Parameter	Coefficient		Description	Coefficient Needed for	
	Symbol	Units		Exact	Numeric
NH3N	$\beta_{8,1}$	per day	First order oxidation rate (Nitrification)	X	X
	$\beta_{8,2}$	per day	First order removal rate	X	X
	$\beta_{8,3}$	mg NH3N/mg CBOD	Stoichiometric ratio	X	X
	$\beta_{8,4}$	mg NH3N/mg ALGP	Yield coefficient		X
	$\beta_{8,5}$	Dimensionless	Weighting coefficient to indicate preference of algae for NH3N over NO3N		X
	$\beta_{8,6}$	mg/l	Half saturation coefficient		X
NO3N	$\beta_{9,1}$	per day	First order removal rate	X	X
	$\beta_{9,2}$	mg NO3N/mg ALGP	Yield coefficient		X
	$\beta_{9,3}$	mg/l	Half saturation coefficient		X
DOXY	$\beta_{10,1}$	per day	Reaeration rate (if this is left blank the model will calculate the reaeration rate using the equation $\beta_{10,1} = 5.58\ V^{0.607}/H^{1.689}$ V = Velocity (m/sec) H = Depth (m)	X	X

TABLE 12. Continued.

Parameter	Coefficient		Description	Coefficient Needed for	
	Symbol	Units		Exact	Numeric
	$\beta_{10,2}$	mg/l	Dissolved oxygen saturation at 20°C	X	X
	$\beta_{10,2}$	m	OPTIONAL: The model will calculate the DO saturation for each reach if "C" is assigned -1.0 and $\beta_{10,2}$ is the elevation of each reach in meters	X	X
	$\beta_{10,3}$	(mg/l)/day	Net oxygen production by phytoplankton	X	X
	$\beta_{10,4}$	$(g/m^2/day)/(mg\ O_2/l)$	Benthic uptake of oxygen	X	X
	$\beta_{10,5}$	$(mg\ O_2/day)/mg$ ALGP	Algae O_2 production		X
TEMP	$\beta_{11,1}$	per day	Air-water transfer rate	X	X
	$\beta_{11,2}$	°C	Air temperature	X	X
	L_{11}	$°C/m^2$	Solar radiation entering the water	X	X
ALGP	$\beta_{12,1}$	per day	Maximum specific growth rate		X
	$\beta_{12,1}$	per day	Algae death rate		X
All Parameters	L_i	$(g/m^2)/day$	Leaching rate from bottom deposits		
	$\bar{R}$	m	Hydraulic radius of reach		
	$\bar{A}$	m^2	Cross-sectional area of reach		

TABLE 12. Continued.

Parameter	Coefficient		Description	Coefficient Needed for	
	Symbol	Units		Exact	Numeric
	Q_S	$(m^3/sec)/m$	Lateral surface inflow/outflow		
	X_{Si}	mg/l	Concentration in lateral surface inflow		
	Q_G	$(m^3/sec)/m$	Lateral subsurface inflow/outflow		
	X_{Gi}	(mg/l)	Concentration in lateral subsurface inflow		

LEVEL 4 R & D RESEARCH AND DEVELOPMENT

Level 4 would develop a complex interactive ecosystem model that would synthesize hydrology, river mechanics, water quality, and food chain dynamics into a unified computer model. There are some knowledge gaps in creating such a model and basic research is required to provide fundamental theories to develop these models, as well as to collect adequate data to calibrate and validate such a model.

While each module can speak to research needs to support the Level 4 methodology development, the water quality module has identified these following critical research issues:

1) The ability to define the risk and reliability of the information produced at each level of analysis so tradeoffs can be made between basic research to improve estimates versus applied research that can devise management schemes that cope with uncertainty.

2) Even at Level 4, the model and methodology do not include socio- and economic forces and lack the feedback linkages of human intervention. Research is needed to determine a hierarchy or framework to introduce these human factors into the methodology.

3) The ability to model eutrophication in flowing streams is inadequate; the shift from phytoplankton to rooted vegetation cannot be modeled. The drift of species diversity and the resiliency of aquatic ecosystems needs to be better understood.

4) The response of the food chain to the presence of sublethal concentrations of toxic chemicals requires extensive study. Criteria need to be developed for water quality including such chemicals. The recycling of these chemicals in the sediments needs to be examined.

The details and specifications for large-scale ecosystem models had to be the subject of another workshop and are beyond the scope of our module.

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MODULE III: INSTREAM FISHERY ECOSYSTEMS

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I. INTRODUCTION

II. THE OVERALL METHODOLOGY

III. THE FISHERY MODULE

IV. NEED FOR ECOSYSTEM PARAMETERS

V. RESPONSE TO SPECIFIC QUERIES

INTRODUCTION

The IFG incremental methodology endeavors to predict consequences of streamflow manipulations on various parameters across a broad spectrum of interests. The methodology is in a state of evolution, therefore it cannot be evaluated as an operational whole. However, it is possible to examine the conceptual basis, and the general methodological approach which is under development. This report concerns the fishery module. Its purpose is to critique those portions of the IFG methodology pertaining to fishes, both as a concept and analytical approach, to suggest avenues for improvement or expansion, and to identify and establish priorities for needed research and development to improve the present day methodology.

THE OVERALL METHODOLOGY

A common assumption associated with quantification of stream flow requirements for fish resources is that if instream flows are adequate for maintenance of healthy fish populations, other instream uses will be generally protected. This is reasonable because the ichthyofauna as a group is sensitive to flow variations and changes in related parameters. Fishes are generally in the upper trophic levels of the aquatic ecosystem, or coupled complexly to other ecosystem sectors, so that existence of healthy fish stocks implies a viable ecosystem. Natural fish populations are a sensitive barometer of ecosystem condition. In addition, fishes are better known ecologically and biogeographically than other aquatic biota.

Past instream flow methods aimed to establish a single or fixed minimum flow. Such an approach is founded on a threshold concept, i.e., fish populations will not be harmed unless stream flows drop below this minimum value. However, fish and invertebrates are adapted to changing flow regimes;

fluctuating water levels are a normal part of stream ecology. But, as water becomes fully appropriated through increased multiple use demands, the minimum flow tends to become the median flow condition; manifested by a flat hydrograph for most of the year. The normal fluctuations to which organisms are adapted are eliminated. Therefore a rigid approach of establishing a single threshold value for minimum instream flow is neither desirable, nor ecologically sound. This realization correctly orients the IFG toward decision-making strategies in the multiple use context. This is a valid, realistic approach for methodology development.

A comprehensive approach to multiple uses makes some sort of classification scheme necessary. The present IFG classification into "complementary" and "delivery" requirements is unclear in intent. The *complementary requirement* is defined as "an instream flow regime which will satisfy several insteam uses at once." Is this a minimum regime, or any regime? If the latter, its utility is uncertain. If the former, then the complementary requirements might usefully be taken to represent that flow above which no management decisions to allocate flows to one use or another would have to be made. The intent and plan of implementation of the complementary requirement are not clear. From Fig. 1,[1/] the complementary flow regime emerges after conflict and impact decisions have been made, and the resulting flows may not complement at all one or more of the multiple uses. The *delivery requirement* consists of additive flows that include consumptive water losses to natural or human processes. The desirable stream flow regime would reflect a combination of both the delivery requirement and the complementary instream flow requirement. The delivery requirement, water removed from a stream by any process or for any purpose, is clear. The complementary requirement should be further clarified, or perhaps a different classification developed.

The focus on institutional aspects to the extent of explicitly incorporating them into the methodology is very positive. Instream flow management is more than scientific analysis because of the many segments of the user community it affects. The intent of the IFG to provide service to user groups is an important step in coupling the technical methodology to applications within and across institutional frameworks.

As presently conceived the methodology is to be developed in eight modules, "necessary to complete a simulation of the physical and chemical dynamics of a stream system."[1/] The modular concept is necessary in such a program as this to provide a capability for alternative resolution levels within modules. A very important stream system may require high resolution based on extensive data sets, whereas for a lesser system low resolution based on scant data may be adequate. Each module should have an adaptive resolution capability based on (1) different intensities of application of a given approach, (2) different approaches, and (3) different technological capabilities among scientific disciplines.

The eight modules identified for development are:

1.	Delivery and return flow	5.	Channel maintenance
2.	Fishery	6.	Estuarine inflow
3.	Recreation	7.	Riparian vegetation
4.	Water quality	8.	Channel design

These modules do not appear to be organized into a framework that constitutes an ecologically meaningful whole. Modules 1, 5, and 8 pertain to hydrology, but not all potentially meaningful aspects of hydrology are included. Modules 2 and 7 represent biology but fail to encompass important aspects of stream ecology. Water quality represents a special aspect of the more basic human use. The estuarine category is as large a subject as all the rest. The

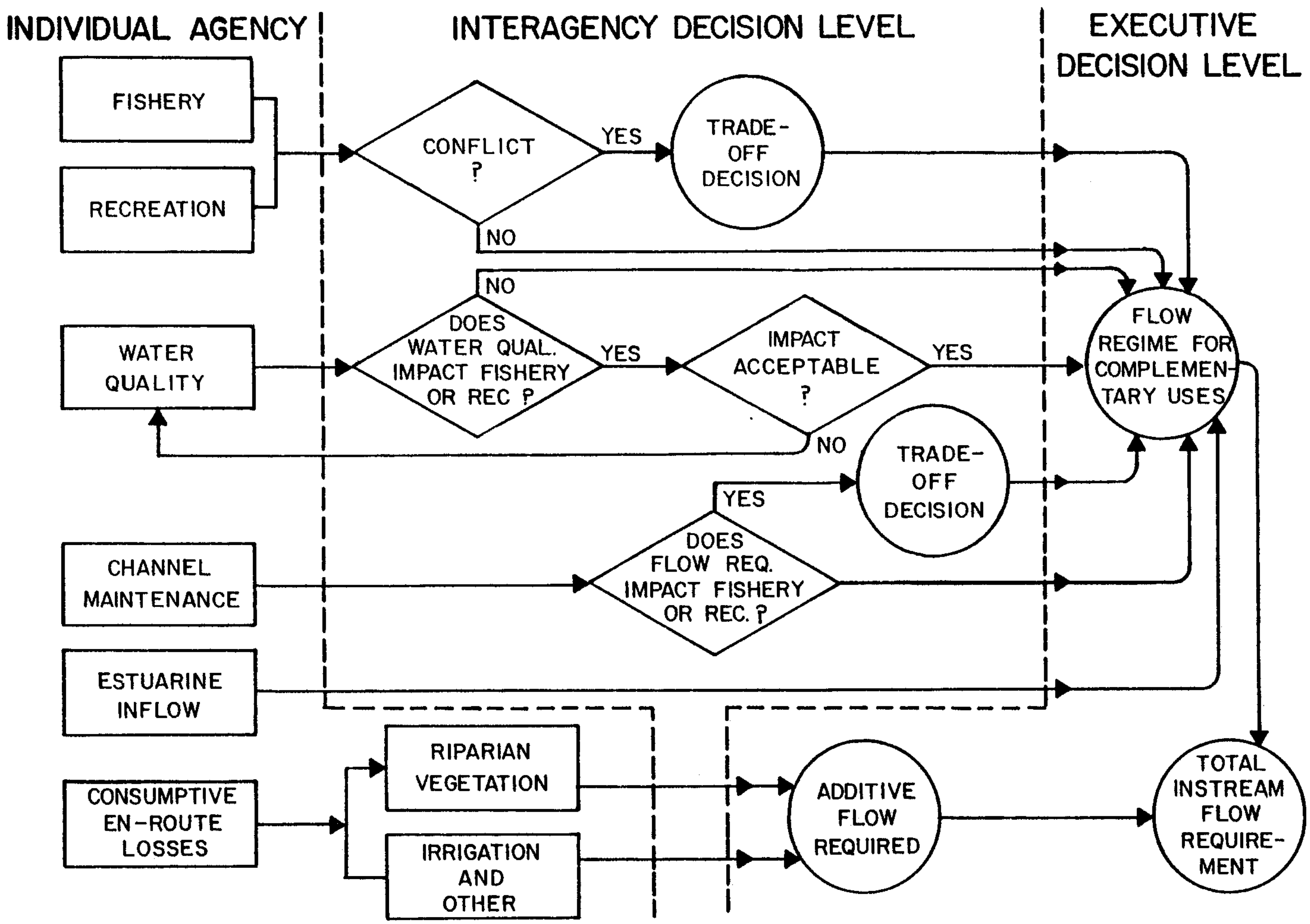

Figure 1. Flow chart for determination of total instream flow requirement.

foregoing discussion has now lead to the first major criticism of the overall methodology: *It is not, nor does it appear to be, a consistent system (whole), but rather a collection of specific modules, designed to meet immediate practical ends that are interrelated by hydraulics.* The non-hydraulic cross connections between the above eight modules, as evidenced by their flow diagrams in Fig. 2-8[1/] are sparse. The overall conceptual design of the approach should be carefully evaluated, and means developed to make it more comprehensive in terms of the ecosystem and multiple use philosophies which IFG espouses.

All relevant aspects of instream flow should be encompassed by an overview model with consistently interacting modules. The present scheme is more piecemeal and it may be difficult to couple modules later in diverse applications. The module set should be reexamined for its comprehensiveness in terms of IFG objectives, and modified as necessary. Then the comprehensive instream flow management plan (Fig. 1) should be adjusted to take account of any changes. In the absence of alterations, the existing modules should still be rectified to Fig. 1 which presently includes only categories 2-7 above. Consistency between module development and the overall methodological plan for use of the modules should be clearly established.

Each module is to be implemented by dynamic simulation modeling. Simulation modeling of large scale ecological systems is in its infancy and currently fraught with many philosophical and technical difficulties. The IFG's methodology reflects pragmatic problem-oriented thinking. But nevertheless, the same basic modeling problems of conceptualization, choice of functions, calibration, coupling and validation are all pertinent to the IFG approach. Simulation modeling of ecological, economic and social systems has been oversold. Simulation modeling for predictive purposes, what the IFG is attempting, is particularly difficult and fraught with pitfalls. Simplifying assumptions must often be made in simulation modeling which compromise scientific standards. All too often, any simulation model that provides even the most vaguely satisfying solutions is accepted truth.

Accurate prediction of time dynamics in large scale ecological systems is the most demanding and difficult objective of simulation modeling. Unfortunately, the existing state-of-the-art does not measure up to desired scientific standards in this regard. Thus, IFG should maintain a focus on the legitimate uses of modeling, cognizant that any comprehensive methodology is bounded by numerous state-of-the-art constraints.

Recognizing these present day constraints while still applying this methodology is within the realm of acceptable scientific behavior. The IFG effort is not unlike other scientific developments in other fields of endeavor. That is to say, basic research, further testing, and refinement must continue; but the present day methodology still has utility as an application of science in resource policy development and decision-making.

THE FISHERY MODULE

The purpose of the fishery module is, "to assess the impacts of altered streamflow regimes on instream habitats."[4/] Five streamflow parameters which directly influence fish distribution are identified: (1) depth, (2) velocity, (3) temperature, (4) substrate, and (5) cover. Three simulations are involved: (1) hydraulic conditions, both normal and modified; (2) impact of stream flows on fishes, invertebrates and other stream biota; and (3) coupling of (1) and (2). Again, hydraulic modeling is central.

Target fish species are classified into five categories: (1) economic, (2) indicator, (3) endangered, (4) nongame, and (5) forage forms. The last group includes also "aquatic invertebrates" which may be important in food chains. This is a modest, if curious, way to acknowledge the existence of a stream community which, with depth, velocity, temperature, substrate and cover, also affects fish populations. The recognition of different functional classes within a species, such as life history stages, is positive.

The IFG group shows a good sensitivity to assumptions, both expressed and implied. Three underlying expressed assumptions for the fishery module are: (1) "that the distribution and abundance of any species [are] not primarily influenced by any single parameter of streamflow, but related by varying degrees to all hydraulic parameters;" (2) "that a species will elect to leave an area when streamflow conditions become unfavorable;" and (3) "that individuals of a species will tend to select the most favorable conditions in a stream, but will also use less favorable conditions within a defined range, with the probability-of-use decreasing as conditions approach the end points of the total range."[4/] Thus arises the *probability-of-use concept which* provides the basis for the IFG Incremental Instream Flow Method.

One possible implication of the IFG's chosen approach leads to a second major criticism of the methodology. The implication is that the specified parameters--depth, velocity, temperature, substrate and cover--are sufficient for determining habitat selection by the fishes. *The criticism is that these factors are necessary, but not sufficient, determinants of fish distribution.*

The logical flaw is demonstrated as follows. Let the statement, "hydraulic parameters are sufficient to specify fish habitats," be put in the form of a *conditional statement* in propositional logic:

$$\begin{tikzcd} \begin{array}{c}\text{hydraulic}\\ \text{parameters}\\ \text{okay}\end{array} \arrow[r, Rightarrow] \arrow[r, bend left, "s"] & \begin{array}{c}\text{fish}\\ \text{habitats}\\ \text{okay}\end{array} \arrow[l, bend left, "n"] \end{tikzcd} \qquad (1)$$

The double arrow is read "implies," or the statement can be read "if hydraulic parameters are okay, then fish habitats are okay." Hydraulic parameters okay is sufficient (s) for fish habitats to be okay, and the latter is necessary (n) for the former. Since the assumption is false, it leads to a false consequence. The *contrapositive* of the conditional statement holds:

$$\begin{tikzcd} \begin{array}{c}\text{fish}\\ \text{habitats}\\ \text{not okay}\end{array} \arrow[r, Rightarrow] \arrow[r, bend left, "s"] & \begin{array}{c}\text{hydraulic}\\ \text{parameters}\\ \text{not okay}\end{array} \end{tikzcd} \qquad (2)$$

The falseness of this statement is obvious; there may not be okay fish habitats for many reasons other than absence of adequate hydraulics; yet the absence of fish habitats is implied to be sufficient for poor hydraulics. The true assumption should be the *converse* of the original false assumption namely, "hydraulic parameters are necessary to specify fish habitats." In logical form this is:

$$\begin{tikzcd} \begin{array}{c}\text{fish}\\\text{habitats}\\\text{okay}\end{array} \arrow[r, Rightarrow] & \begin{array}{c}\text{hydraulic}\\\text{parameters}\\\text{okay}\end{array} \arrow[l, bend left, "n"] \end{tikzcd} \qquad (3)$$

The inverse of the original conditional statement,

$$\begin{tikzcd} \begin{array}{c}\text{hydraulic}\\\text{parameters}\\\text{not okay}\end{array} \arrow[r, Rightarrow] \arrow[r, bend left, "s"] & \begin{array}{c}\text{fish}\\\text{habitats}\\\text{not okay}\end{array} \arrow[l, bend left, "n"] \end{tikzcd} \qquad (4)$$

is a true consequence of the converse. Thus, if the hydraulic parameters are unsatisfactory, this is sufficient for not okay fish habitats, and the latter is necessary for not okay hydraulics. Note the difference between statement (1), which is false, and statement (4), which is true. The IFG incremental methodology is based on statement (1) when in fact it should be based on statement (3). Hydraulic parameters are necessary to specification of fish habitats, but they are not sufficient. The present IFG methodology focuses heavily on necessary conditions for fish habitats, but does not adequately incorporate sufficient conditions. To the extent that the present methodology does not establish a basis for impacts of altered streamflow regimes in "sufficient conditions," it is operationally inadequte.

Based on the expressed assumptions, an associational approach to relating fish distribution to hydraulic conditions is formulated. Of two possible approaches, (1) establishing causation or (2) observing correlations, the latter is weaker in the logic of inference. The IFG methodology is correlative only, and will be less defensible and justifiable in an adversary setting than would be approaches that gave causal explanations. In the context of resolution, the correlation approach might be considered a low resolution counterpart of an eventual high resolution causal method within the fishery module.

Probability-of-Use Curves

The basis for the IFG's incremental methodology lies with its "probability-of-use" information expressed in a curve format. These curves do not represent true probabilities, and should, therefore, be renamed. e.g., *habitat desirability curves.* Four types of analyses were employed to formulate the initial curves. In descending order of the quality of curves produced, these are: (1) frequency analysis, (2) range and optimum analysis, (3) parameter overlap, and (4) indirect parameter analysis.[4/] The rationales underlying these methods, and the methods themselves, constitute a major positive feature of the IFG methodology given the commitment to a correlation approach. Each method of curve construction utilizes a specific, objective procedure consistently employed. *Frequency analysis* is based on data available consisting of depth, velocity and substrate at capture or observation locations for individual fish. The clustering of frequency increments by a systematic procedure to reduce variance appears reasonable, but statistical consequences should be evaluated. *Range and optimum analysis* is based on range and optimum information when frequency data are not available. Some subjectivity is involved in "drawing" a bell shaped curve through four data points, but this is unavoidable. Also, a normal distribution is assumed in absence of other information. The statistical validity of this choice for the type of data and systems involved should also be evaluated. Parameter overlap converts field descriptions of habitats used and avoided to approximate range and optimum data, and curve construction then follows the same general procedure as in the previous method. *Indirect analysis* is, apparently, a set of ad hoc methods by which information for curve construction is drawn principally from the biologist's intuition and experience.

The habitat desirability curves that result from these procedures are then given a quality rating, based on specific objective criteria. This is an excellent feature of the methodology that should aid decisions in establishing instream flow regimes and serve well in proceedings to resolve conflicts.

Methods for obtaining data are described,[4/] and should also be reviewed by specialists in sampling theory so that qualifications can become known and stated.

IFG Incremental Methodology

The incremental methodology based on habitat desirability curves quantifies the amount of potential habitat available for each species or life history stage, in a given stream section, under different streamflow regimes, and with different channel configurations. The method consists of four steps. (1) Physical stream measurement utilizing multiple transects; (2) Hydraulic simulation of the stream reach to determine spatial distribution of combinations of depths and velocities associated with bottom and cover types at different stream flows. (3) For each target species or life stage, a "composite probability-of-use" (i.e., *composite habitat desirability index*) is calculated for each combination of hydraulic parameters represented in a stream segment. These composite indices are determined from the individual habitat desirability curves for the separate parameters as a simple product of the separate desirabilities.[4/] This procedure introduces an implied assumption that organisms select among the parameters in a fashion of statistical independence. Obviously, depth, velocity, substrate and cover are not independent variables of themselves, and may not be in terms of how fish select for them. Statistical dependence in selection among parameters should be a subject of research. Subsequently, the composite desirability indices should be computed in an analogous manner to joint probabilities between statistically dependent variables. (4) Finally, a *weighted usable area* for each reach is calculated for various stream flow levels by species for life history stage multiplying surface area for each hydraulic combination (step 2) by the composite desirability index (step 3). The weighted usable area is accepted as an index of attractiveness of a stream reach in areal terms for each species or life stage. Weighted usable area plotted against different flow regimes can be used to identify critical periods for each life history stage, and availability of limiting habitat for each stage or species.

The incremental method appears sound as a computation procedure, except for the need to determine interaction effects among depth, velocity, substrate and cover with respect to the habitat desirability. However, because of the implications associated with the necessary versus sufficient trap, it is not generally recommended to determine habitat selection based on hydraulic parameters alone. The IFG authors state, "Since changes in hydraulic characteristics will initiate differential species reactions, the incremental method may be particularly useful in predicting changes in species composition. Because the output from the incremental method is directly tied to the physical carrying capacity of the stream, it is possible to determine the approximate change in standing crop of a given species at different instream flow regimes.[4/] However, until the methodology can be based on a parameter set--physical, chemical and biological--not only necessary but <u>sufficient</u> to specify fish production, such application should not be oversold.

NEED FOR ECOSYSTEM PARAMETERS

In summary, two major criticisms of the IFG incremental methodology have been identified:

1. The methodology is not a consistent system of strongly interacting components, but a collection of specific modules interrelated by stream hydraulics.

2. The methodology, as presented, is based on a narrow set of physical parameters providing necessary, but not necessarily sufficient, conditions for the specification of stream habitats.

These are fundamental conceptual criticisms originating as a result of the methodology's strong orientation toward water management decision-making. There is virtually no acknowledgement in the present IFG literature that stream ecosystems exist or that their status is relevant to the existence and status of fisheries. This should be remedied. Changes in instream flow regimes have both direct and indirect effects on fishes. Direct effects are expressed when flows approach or exceed tolerance limits, hence certain flow characteristics are necessary for the well being of target populations. But, within the range of tolerances, habitat desirabilities are determined by other ecosystem parameters that reflect primary production, trophodynamics, decomposition and nutrient regeneration. The flow regime affects all ecosystems processes, and hence under non-extreme conditions its effects are propagated to the fishes indirectly via ecosystem structure and function. Sufficient parameters to specify stream fishery habitats therefore reside in the particulars of extant ecosystems in each stream reach. A rigorous written discussion of these indirect effects and guides for examining, accepting or rejecting simplifying assumptions should be developed for IFG methodology users.

Although the IFG methodology is portrayed as a general approach, there is a persistent bias toward the dominance of physical factors which has come from experience with western stream studies where physical factors are the principal determinants of fish distribution. Important biological factors in microhabitats and selection within a stream reach include: (1) keystone species, (2) trophic dynamics, (3) space competition, and (4) status of predation. The universal assumption of physical factor dominance is tenuous; as is the implied assumption that a species in different ecological settings always behaves similarly. Plasticity in habitat selction is extremely important. Thus, a fundamental problem with the methodology is the assumption that fish are physically limited rather than food-chain limited. This also reflects the western bias. In eastern streams food is often both the ultimate limit of fish production and the immediate reason for low production. Some species are limited by external factors such as harvesting. Considering the entire ichthyofauna, physical factors are seldom limiting under natural conditions. Under all but extreme natural conditions fish and invertebrates both tend to be food limited in eastern waters.* Answers to fundamental questions such as the following need to be built into the methodology: (1) How are instream nutrients, expecially NO_3 and PO_4, affected by flow modifications? (2) How does the flow regime influence nutrient effects on primary production? Nutrients in return flow may be especially important. (3) How is stream primary production affected by physical factors such as flow, temperature, sediment load, etc. (4) How important are allochthonous vegetation inputs to primary production, and how will flow regulation and watershed

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* Editor's note: One intended application of the IFG methodology is identification of those activities of man which would so alter the natural flow regime as to result in conditions of stress normally found only with extreme natural conditions.

management influence the quantity and qualtity of allochthonous inputs? (5) How do physical and chemical factors affect connections between food base productions and fish production, or detritus decomposition and invertebrate production?

Implementation of an ecosystem holistic viewpoint by IFG can overcome both of the two major criticisms. Addition of modules designed to develop diagnostic information about the state of the stream ecosystem would assure a more strongly connected set of mutually consistent components for the incremental methodology, as well as base the methodology on a broader parameter set to establish sufficient conditions for specifying fishery habitats. Obviously, full ecosystem information is beyond the scope and intent of the IFG methodology. Therefore, the same basic approach as presently used can continue to be employed, but extended to several additional parameters that reflect chemical and biological processes of ecosystems.

The following set of parameters incorporate chemical and biological as well as hydraulic considerations. Seven major parameters, in order of importance, are:

1. depth
2. velocity
3. temperature
4. food supply
5. riparian cover
6. competition
7. predation

Six additional parameters of lesser significance, unranked, are:

8. substrate
9. dissolved oxygen
10. instream cover
11. nutrients
12. stream morphology
13. sediment load

Dissolved oxygen and nutrients are constituents of water quality, a graded approach to which illustrates how other categories might be examined. Water quality could be assessed at several levels of resolution. First is a screening level in which it is only necessary to establish the absence of lethal concentrations of toxins. At the second level temperature and dissolved oxygen concentrations would permit an estimate of stream ecosystem metabolism for a small additional monitoring investment. Level three would introduce conductivity and turbidity measurements to assess dissolved and suspended solids. The fourth level would add to the previous list information about nitrate, phosphate, other nutrients and perhaps toxicants. Food supply, competition and predation are biological variables. To assess biotic conditions of a stream, indicator species, keystone species and species richness (diversity) should be examined by quick survey techniques. For example, artificial substrates introduced some weeks before sampling would provide diagnostic data on instream productive potential. Food chain information could also be developed based on a few relatively simple measurements.

There are four potential food sources in streams:

1. benthic primary production
2. planktonic primary production
3. within-reach allochthonous inputs
4. stream channel allochthonous inputs

Each of these is directly or indirectly affected by instream flows. These effects and their propagation through food chains to fish abundance can be evaluated with fairly simple models based almost entirely on parameters already in the IFG methodology, as outlined below.

Factors needed to estimate benthic primary production are temperature, nitrogen, phosphorus, light, substrate, and geographic region. Given these factors a model, perhaps little more than an expansion of Michaelis-Menten formulation, could be used to estimate benthic primary production. A similar model, using the same factors with the exception of substrate, could be used for planktonic primary production. Within reach allochthonous inputs could be generated in a fashion similar to estimation of overstream cover from measured values of stream and floodplain width, and knowledge of riparian vegetation in the study reach. Estimation of stream carried allochthonous inputs is a more difficult problem, one that should be recognized as an area of research need. Three possible approaches are suggested: (1) From a large number of particulate organic matter samples, a site-specific model could be developed and calibrated. (2) It may in the future be possible to develop a predictive model based on upstream watershed characteristics. (3) Particulate organic matter could be estimated from predicted or measured levels of total suspended solids. Based on current lack of information about utilization of dissolved organic matter, its inclusion in a model is not recommended. Avenues for refinement of each of these estimations of energy sources should be evident, for example, breaking down benthic production to diatoms, filamentous algae, and macrophytes; treating limiting effects of trace nutrients; and partitioning particulate organic matter into size fractions.

The next step is to convert energy source estimates to secondary production estimates. Again, as a start, a simple two-step procedure might suffice: (1) determination of the presence of appropriate consumer guilds, i.e., benthic grazers, filter feeders, or shredders; and (2) estimation of consumer production based on trophic efficiences. The approach used to evaluate habitat desirability for fish could also be applied in general to invertebrate consumers. One area of modification would be more refined treatment of substrate classes. For the purposes outlined here, invertebrates could be lumped into guilds with each guild represented by a broadly tolerant species since only presence needs to be established. The trophic efficiency technique is probably the weakest step of the suggested procedure, however, no simple alternative exists. This represents another area of research need, for example, how do leaf or algal species affect assimilation and respiration? How efficient are passive filter feeders in capturing suspended organic particles? Are consumers selective in their feeding?

The end result of these calculations would be an estimate of potential consumer productions which can be used to complement estimates of weighted usable area. These outlined procedures also provide a framework for further development and refinement.

RESPONSE TO SPECIFIC QUERIES

A number of questions were posed at the workshop. Responses to many of these are given below in accordance with the ecosystem philosophy espoused above.

1. What are the strenghts of the IFG methodology conceptually and procedurally? Conceptually, the method is geared to provide a service to user groups, and technical aspects of the problem are coupled meaningfully to institutional considerations. The modular construction is desirable although choice of modules and the overall framework within which they are to interact are issues. Also, several levels of resolution within each module should be available to adapt the methodology to problems and data sets of different magnitudes. Procedurally, hydraulic simulation is the obvious strong point of the methodology. The "probability-of-use" concept is a normalized index and not a probability, and should be calculated and interpreted accordingly. "Weighted usable area" is difficult to interpret. For example, 10^4 ft^2 with a desirability index of .01 is equivalent to 100 ft^2 of excellent habitat. If an adjacent reach has 50 ft^2 with a desirability value of 1, that is where the fish will be. In other words, the use of weighted usable area assumes additivity of elements of goodness regardless of spatial distribution. An alternative to weighted usable area should be sought.

2. What are the advantages and disadvantages of the hierarchical, modular approach of the IFG methodology? The modular approach should be retained. Choce of modules within a total system framework to overcome the first major criticism should be reevaluated. Also, modules should be developed with different data requirements for different resolution levels.

3. In what priority should various physical, chemical and biological models be pursued? In response to the second major criticism,

parameters required to establish sufficient, and not just necessary, conditions for fish habitats need to be developed. This development should be integrated, making use of easily measured variables as outlined in the previous section. With the use of simple models primary variables can be used to generate derived variables reflecting ecosystem condtion.

4. What state-of-the-art technology is readily available for adoption or adaptation to instream flow assessments? Multivariate statiscal analysis has not been explored as a possible alternative to the IFG methodology. These methods should be examined both in their complementary and alternative resolution aspects. Ecological simulation modeling is sufficiently well developed to be incorporated judiciously into the IFG approach.

5. What areas of validation research require more emphasis? The apparent bias of the present methodology toward western stream has been mentioned. Less is known about lotic systems in the western United States than in eastern North American and the Mississippi valley. Two kinds of validation should be sought, intensive and extensive. For intensive, rigorous testing in regions where large data bases exist should be undertaken, i.e., in salmonid streams of the Pacific northwest. Extensive testing should cover a broad range of physiographic provinces, concentrating first on eastern salmonid streams for comparison with western results, then extending to mainstream rivers and non-salmonid species. The present physical bias of the methodology may possibly be acceptable in the west, but in the east, fish habitats will be determined by other physical and chemical parameters.

6. What other parameters should be added to the methodology? A total of 13 parameters was indicated in the preceding section 5 to 7 of which appear to be new.

7. What emphasis should be placed on factoring other components (riparian vegetation, wildlife, estuarine inflows, etc.) into the assessment method? Considerable. Major criticism number one calls for an integrated, holistic methodology in which the modules are exhaustive over all significant problem areas, and meaninfully integrated.

8. What new areas of frontier research are required? The basic ecology of streams is still a vast unknown, including the biology of even major aquatic species, their interactions, and ecosystem level relationships. The IFG methodology can be no better than the knowledge base on which it is formed. Basic study of stream ecology over a broad spectrum of stream types and regions should be encouraged. IFG can serve such a purpose through the data requirements of its alternative modular methodologies, pointing to information gaps and defining useful forms of information to be collected.

9. Is the representative reach a valid decision making tool? Yes. The representative reach is conceptually a stratified random sampling scheme. The choice of actual study reaches should be in accordance with requirements of rigorous sampling theory to assure results that can be employed with confidence at the level of decision-making. Professional statisticians should be consulted to develop specific criteria.

10. Does the independence of variables influencing species distribution implied by the computation procedure appear to be valid? No. This is a major technical problem with the present methodology. There are only two reasons to accept such an assumption: (1) lack of positive reasons to adopt any other formulation, and (2) the form of available data. It could be argued that even if only 5% of available data did not conform to the independence assumption, a multivariate analysis would be significantly more reliable than the IFG methodology. This might be true anyway, and established multivariate

methods should be evaluated for instream flow assessment and performance compared to the IFG approach. As to alternatives, let G be a scalar denoting habitat desirability of a site. Let f_i be a scalar parameter, where i = depth, velocity, temperature, etc. spanning the 13 factors listed above. Then $G = \phi\ (f_1, f_2, \ldots, f_n)$, where ϕ is some integrable function mapping a point $(f_1, \ldots, f_n)$ into the scalar value G. IFG has assumed that $G = \Pi_{i=1}^{n}\ g_i(f_i)$, where g_i is some unitless function of factor i (e.g., a frequency distribution normalized to 1, a probability function, etc.). Further, since G is computed for each habitat subvolume, the aggregated value G^* is defined as a summation $G^* = \Sigma_{j=i}^{N}\ G_j$, of the N subvolumes of the study reach, where G_j is the desirability of the j'th subvolume. Two methods to determine G are by power series,

$$G = \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} \ldots \sum_{k=1}^{N_k} \alpha_{ij\ldots k}\ f_1^i\ f_2^j\ \ldots\ f_n^k,$$

or by discrete approximation. The power series approach is essentially impossible to parameterize except by a least squares fit to an extensive data set. Therefore, discrete approximation is recommended. In this approach the range of each factor f_i is segmented. Then an n-dimensional matrix, with each entry reflecting the utility of a habitat exhibiting each combination of segmented characteristics, is constructed. Instead of computing weighted usable area, a histogram of volume units having each value might be constructed, from which mean, median, percent of volume units with better than 50% desirability, etc. could be computed.[5/]

11. Is weighted usuable area an adequate concept upon which to build and defend decisions about instream flows? Even if the computations were based on sufficient conditions to establish habitat desirability for fishes,

weighted usable area would not be an adequate concept. As discussed above, a large number of units of marginal habitat is not the ecological equivalent of a small number of units of prime habitat. However, as an interim or low resolution approach, weighted usable area serves a useful purpose.

12. Is the implicit assumption of the incremental method, that fish production is a function of "usable habitat," valid? Usable habitat could correspond to used habitat if the former were defined by a sufficient set of parameters. In other words the assumption is reasonable in principle. The effort to establish sufficiency will, in general, be geared to the importance of the specific project.

13. Assuming a known functional relationship between weighted usable area and fish production, what is the best approach presently available to relate population dynamics to the "habitat dynamics" produced by the incremental method? Simulation modeling. The previous section outlined an approach by which information derived from relatively simple to measure parameters could be extended by simple models to derive parameters reflecting the state of the stream ecosystem.

14. Should data for the incremental method be collected and analyzed by region? Should they be catergorized by stream size? Yes. For development of a general methodology variability over a range of stream types and geographic regions should be assessed. Delphi approaches to the generation of "soft" data sets should certainly be used.

15. Would it be desirable to place confidence intervals around the habitat desirability curves? Certainly, if sufficient data can be obtained to permit this. The present scheme of quality ratings is a good practical approach, however.

16. Is the traditional approach of developing criteria by LD_{50} laboratory test appropriate? No. Extrapolation of laboratory data to the field should always be done with caution. Information derived under actual field conditions is most desirable.

17. Is the proposed model for cover, paralleling that for composite probability of use, adequate to describe the behavioral response of a species to cover? It would have the same generic problems as discussed for the general methodology. A regression approach might be more recommendable.

18. Is the proposed functional classification of macroinvertbrates (shredders, swimmers, burrowers, etc.) satisfactory? Yes. It is probably quite adequate for even high resolution modules. As stated previously, indicator and keystone species should be taken into account.

19. Should the above classification be replaced by diversity indices? No. The functional approach is much to be preferred. However, diversity measures are diagnostic for stream ecosystem condition and are to be encouraged provided they do not obscure the primary data (species lists and abundances) upon which they are based.

20. Is substrate size an adequate descriptor to establish utility to aquatic invertebrates, and should a substrate index be used? Yes, particle size is adequate in the necessary sense, but sufficiency still would need to be established in particular cases. Indices are recommended, again so long as they do not obscure the primary data.

In summary, the present IFG methodology gives incomplete attention to stream biology and to the state of the stream ecosystem as a requisite for fish habitat. Subsequent improvements should strive to achieve a strongly interacting set of modules, holistically derived, and emphasizing the need to establish sufficient and not merely necessary conditions for stream habitat specifications.

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MODULE IV: THE RELATIONSHIPS BETWEEN RECREATION AND INSTREAM FLOW

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INTRODUCTION

This paper has been written in response to methods proposed by the Cooperative Instream Flow Service Group (CIFSG) for evaluating the relationships between the recreation potential of a stream and instream flow. The purposes are (1) to evaluate the proposed methods, (2) to suggest specific improvements and/or areas where improvement is needed, and (3) to identify specific research needs.

The ideas expressed are the responsibility of the authors. The CIFSG and especially Ron Hyra deserve much credit, however, for raising the questions in a way that has prompted our effort. We also wish to acknowledge the important contributions of participants in the November, 1978 CIFSG Workshops in Fort Collins, Colorado. Some of the material presented here is original and is based on research recently supported by National Science Foundation Research Applied to National Needs and the U.S. Forest Service. We also wish to give credit to James S. deBettencourt, a doctoral student at Northwestern University, for the contributions from his research on "Utility Threshold Theory."

THE CIFSG MISSION

As the demands for water grow, the competition for available supplies intensifies. Water left in streams tends to decrease in quantity as well as quality, resulting in damage to the recreational and aesthetic uses of the streams. Because of this increasing competition for water, the dwindling supply of water for stream recreation and the growing demand for recreation, it is no longer safe to assume that recreation needs will be served adequately by the water that is left over when other purposes have been satisfied.

Past efforts to develop methods for evaluating instream flow requirements for recreation and related purposes have been inadequate and not widely accepted. An important effort to address these problems was undertaken recently by an interagency task force established by the Bureau of Outdoor Recreation and chaired by William Honore. The task force addressed three important purposes:

(1) to develop ways to quantify water requirements for instream recreational use;

(2) to develop methods for evaluating streamflow impacts on recreation; and

(3) to determine monetary and non-monetary benefits of instream flow for recreation.

Criteria affecting recreational use of instream water were suggested, methods for measuring the criteria were established, tested and described; and a procedure for analyzing the criteria to determine the relationship to recreation was developed. The results are summarized in a two-volume report, "Recreation and Instream Flow" (Bureau of Outdoor Recreation 1977). The "Principles and Standards for Planning Water and Related Land Resources," developed by the U. S. Water Resources Council and approved by the President on September 5, 1973, require that "beneficial and adverse effects of a proposed plan should be measured by comparing the estimated conditions with the plan, with the conditions expected without the plan" (U.S. Water Resources Council, 1973). One of the obvious but often neglected effects of such a plan might be to change the quantity and quality of instream water available for recreation. This issue becomes even more important in light of the amount of public money to be used to make waters fishable and swimmable under provision of the Clean Water Act of 1977. But, currently available methods do not allow proper comparison of the recreation benefits of instream flow with and without a planned project. Therefore, it is difficult to know where and how much to invest in upgrading stream flow for recreation.

The recent Water Policy Reform message of the President, delivered on July 6, 1978, emphasized protection of instream flows for recreation, water quality, aesthetics, and fish and wildlife habitat. His message suggested Federal or other water programs can create serious problems when they emphasize agricultural, municipal, and industrial uses of water without proper consideration of the need to leave water in the stream. One of the task forces established on July 12, 1978 to implement the provisions of the Water Policy Message concerned instream flow. The purpose of this task force was to explore methods for protecting instream uses in the operation and management of existing water resource projects and to provide for needed stream flow in proposed project plans. Federal agencies were directed to provide technical assistance to states to provide for the maintenance of instream flows.

Against this background the CIFSG is attempting to develop quantitative methods that will serve the above purposes. To be sure, the work of the

CIFSG to date has been somewhat narrow in focus and suffers from several important weaknesses, which we intend to point out and help to correct. The work is an important step in the right direction, however, and there are strengths in the approach as listed below:

(1) The aim is toward quantitative standard methods and measures which have general validity and applicability.

(2) The approach is based on efficient description of stream conditions through sampling and simulation.

(3) An analytical approach is used, which promises to allow powerful, efficient and rigorous investigation of the issues. The use of analytical language is the hallmark of mature and successful science.

(4) The effort to be theoretically and conceptually rigorous has created a powerful articulation of precise questions as well as demands for specific information and operational definition of terms.

(5) Corollary to this last point is the fact that the approach has generated a new set of questions for tributary disciplines. Recreation scientists, fish biologist water quality experts, and stream hydrologists and morphologists are being asked to rearrange their knowledge in very specific ways.

(6) The effort comprises a program of developmental education. By attempting to develop rigorous standard methods for analyzing the relationships between recreation and instream flow, the CIFSG has spawned an educational process. Whether or not the operational goals are achieved, the contributions to the understanding of the problems and ability to deal with them will be great.

As we understand it, the mission of the CIFSG vis-a-vis recreation is to develop methods for analyzing the relationships between recreation and instream flow and to make those methods generally applicable to (1) assessment of the recreation potential of a stream, (2) specification of instream flow requirements for recreation, and (3) assessment of the impact on recreation potential of instream flow. Thus far they have fallen short of these goals, probably by wise intent, and have chosen to address some very narrow questions; namely, (1) how to assess the impact on the potential for certain kinds of instream recreation of changes in depth and velocity, and (2) how to use representative reaches and hydraulic simulation to describe the depth and velocity characteristics of a stream.

SUMMARY OF THE PROPOSED METHODOLOGY

The recreation assessment methodology is a hybrid of the methods previously developed by the CIFSG for assessing the impact of flow changes on fish habitat. In the proposed methodology (Hyra, 1978), depth and velocity are the only hydraulic variables considered. Two methods are proposed: (1) the single cross-section method; and (2) the incremental method. In the single cross-section method, only the critical transect is measured. This is the cross-section that is most likely to prevent a given use due to insufficient depth, excessive velocity, insufficient width, etc.

In the incremental method the quantities of surface area offering various combinations of depth and velocity are calculated by means of transect measurement and hydraulic simulation. Criterion functions are also estimated, showing for various recreational activities the probability that various combinations of depth and velocity will be acceptable.

The criterion functions and the "hydraulic areas" are then used to calculate the "weighted usable area" for the stream. This is obtained by multiplying the surface area of a given combination of (or combination of ranges of) depth and velocity by the associated probability of use. This weighted usable area is the criterion measure used to assess capability of the river to support the type of recreation in question. Obviously, comparisons can be made among several different streams or for the same stream at different rates of discharge.

Alternative methods for assessing the impacts of stream flow changes on recreation and aesthetics are discussed in Andrews, et al. (1976) and Masteller, et al.(1976). Other methodologies have been developed which are not reviewed in this paper or by Hyra (1978) such as Chubb (1976), deBettencourt and Peterson (1977), and deBettencourt (1979). The deBettencourt and Peterson methodology is closely related to the criterion functions in the CIFSG methodology, but it is not based on hydraulic simulation. The aim of the deBettencourt-Peterson paper is to develop a "probability of acceptability" concept from utility theory and empirical experimentation. The analysis is not in terms of depth and velocity; rather, it is in terms of such things as skill level, water quality, level of use, and degree of development. The functions are based on theory and methods which allow for tradeoff and interaction among the variables.

AN OVERVIEW OF THE PROBLEM

There are four general components in the CIFSG problem. One concerns the relationship between recreation potential and instream flow--the criterion component. A second is concerned with the description and prediction of the instream flow characteristics of a given stream--the resource description component. The third is the use of the criterion component to measure and interpret the meaning to recreation of the instream flow characteristics described or predicted for a given stream--this is the evaluation component. The fourth is the practical question that needs to be answered--the application component.

Figure 1 is a flow chart showing how the four components interrelate. Obviously, each could be dissected in great detail, but the decomposition of the flow chart into four major components represents our interests, our beliefs about where the problems are, and our ability to contribute constructively. The principal challenge to the CIFSG is in the criterion component, where there may be serious holes in the state-of-the-art with respect to (1) substantive knowledge about recreation, and (2) methods to formulate and apply criteria. Consequently, our principal emphasis in this paper is on the criterion component.

The Criterion Component

The problem is to develop ways to measure and interpret the meaning of stream flow to recreation. There are at least five serious needs:

(1) The nature and structure of recreation, vis-a-vis instream flow needs to be specified. In talking about fish habitat we can identify "species" with unique habitat requirements, and we can specify at least some of the parameters that are of concern. What are the recreation "species?"

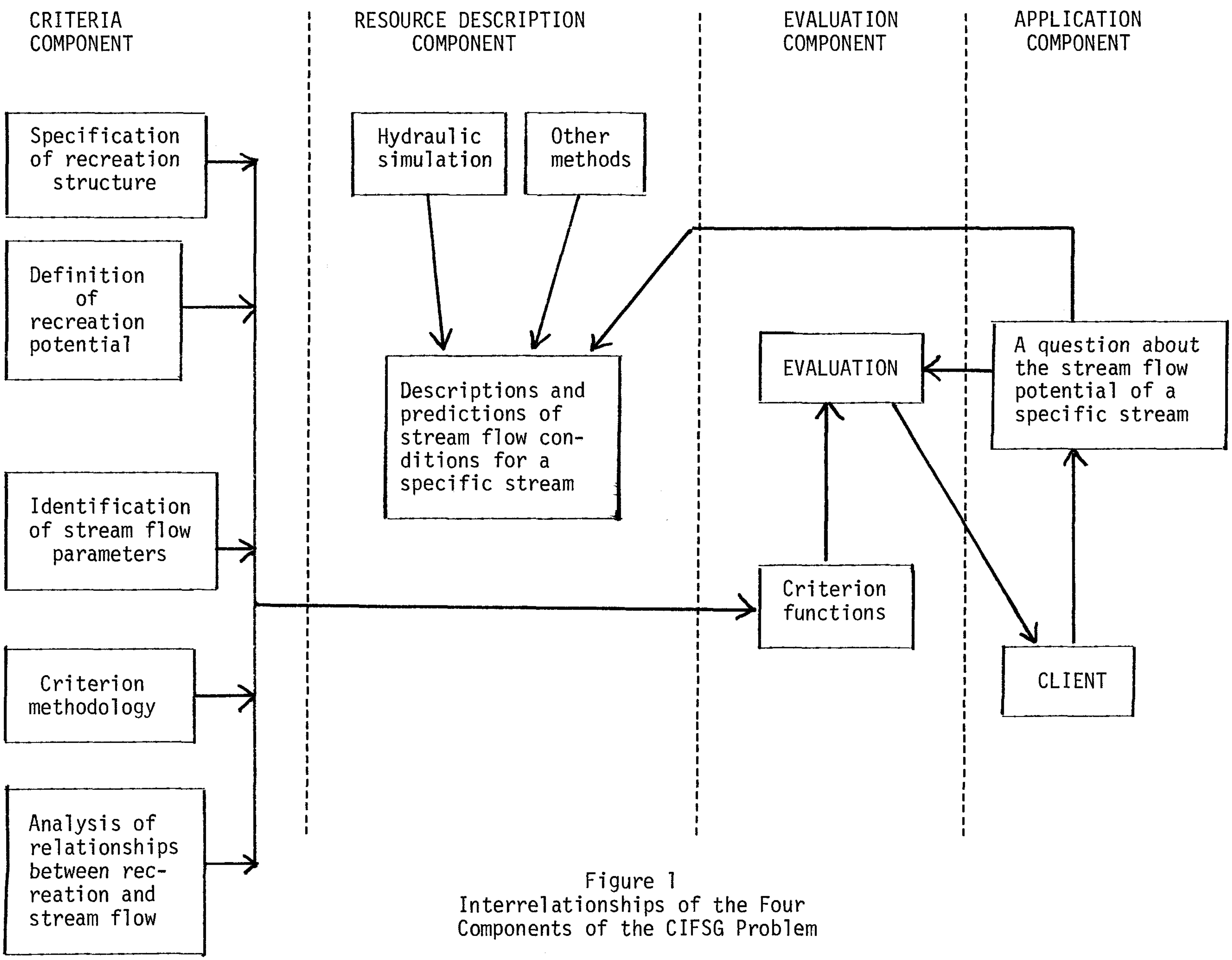

Figure 1
Interrelationships of the Four Components of the CIFSG Problem

(2) We need a far more rigorous definition of "recreation potential" than is presently available. The definition must be strictly operational, not loosely phrased in glib generalities.

(3) For each recreation "species" we need to identify those parameters of or related to streamflow which are of significance.

(4) We need a "criterion methodology;" that is, a framework or strategy for constructing and applying criteria.

(5) Finally, we need to understand the processes by which instream flow affects recreation potential. Given these five sets of information, they can be put together into "criterion functions," or rules, possibly mathematical rules, for measuring the recreational meaning of instream flow.

Resource Description Component

Assuming that the needed criterion functions are available, they will be written in terms of those variables of the stream and its environment which are important to recreation potential. To evaluate a specific stream, it is necessary to measure or describe the stream in terms of those variables. There are many ways this might be done. The CIFSG has chosen to use an approach based on measurements of the stream at sampled representative reaches and hydraulic simulation of the stream flow (Bovee and Milhous, 1978). In addition to the narrowness of the scope of this approach, there are many questions that need to be examined. They will be identified in a later section.

The Application Component

This is the practical question that needs to be answered. Somewhere a client such as a State Department of Natural Resources or a Federal agency wants to assess the impact of a proposed project on a specific stream; or, perhaps there is a stream with established recreation use and it is necessary to determine the stream flow requirements for those uses, so that the water can be used for other purposes to the maximum extent possible without excessive detriment to recreation.

Whatever the final form taken by the CIFSG methods, there are three critical questions that should be asked: (1) can the methods answer the important practical questions; (2) can they do it cost-effectively; and (3) are they the best methods that might be used?

Evaluation Component

Given the criterion functions, a practical question, and a description of a stream under the conditions defined by the question, the next step is to come up with a meaningful answer. Some calculus or framework is needed for putting all the intricate details together into an understandable pattern of information. The CIFSG has proposed the "Weighted Usable Area" as a way to put it all together. The WUA will be discussed in detail later in this paper.

RECREATION BEHAVIOR AND THE ROLE OF STREAM FLOW VARIABLES

In order to evaluate the proposed methodology properly, we must first understand the subject to which it is to be applied. This means that we need to understand the process by which stream flow variables influence the recreational use of the stream. We also must separate the important relationships and changes from those that are unimportant.

Recreation is voluntary behavior. It is people doing what they want to do during leisure time; time that is not owned by someone else. River recreation is such voluntary behavior that is dependent in some way upon the presence and condition of a river.

River recreation may occur in connection with a private sector industry or a public sector industry. In the private sector, commercial operators may be offering services, equipment, and facilities with the intention of maximizing profit. In this regard we are concerned about economic impacts of changes in stream flow. That is, changes in stream flow may alter the quality or quantity of the product or service being offered and may change the firm's ability to attract customers.

There are many reasons why recreational services and facilities are often provided through a governmental agency. Public investments in recreation are frequently made, which on face value may appear to be uneconomical because they (1) provide opportunities for people who would otherwise be unwilling or unable to pay, (2) divert land and other resources away from other profitable uses, and (3) promote intangible and sometimes invisible social and personal benefits which are not readily evaluated. Such investments are made because society, through political processes, has expressed social welfare objectives which cannot effectively be achieved through profit-motivated private enterprise. The achievement of these social objectives in the case of river recreation may be directly related to stream flow variables. Changes in those variables may interfere with, magnify, or redistribute the personal and social benefits generated by public investments in recreation. Because people make numerous private sector expenditures in connection with their use of public facilities and services, there will be direct impacts on the private economy as well.

Thus, recreation can be viewed as an instrument whereby personal and social benefits can be generated and as an industry in which income and economic activity are generated. Changes in the resource base on which the instrument and industry so intimately depend can make a lot of "waves." Prediction of the "waves" caused through recreation, by changes in stream flow, is the task addressed by the proposed methodology. However, as it now stands the methodology addresses only a small part of the question: the first-order impacts of changes in depth and velocity on the probability that people will judge the stream to be acceptable for a given activity. To answer even this very restricted question, we have to understand the behavioral process by which people accept or reject river recreation alternatives.

A reasonable framework for understanding the relationship between stream flow and recreation can be obtained from recent work in behavioral demand assessment (Anas, et al., 1978). The following are major components in the relationship:

(1) The psychological outcomes are the reasons why people engage in recreation. These outcomes are defined in terms of the functions performed by recreation in satisfying personal motives or needs and in generating

personal benefits (Driver and Brown, 1975; Driver, 1977; Lancaster, 1966; Tinsley, 1977).

(2) The <u>activity purposes</u> are the roles and forms taken by recreation. These are the things the person does in connection with the river, such as fishing, swimming, boating, camping, etc. One is attracted to a site and/or activity purpose because of the psychological outcomes expected, but it is the activity purpose that is apparently the conscious objective.

(3) The <u>activity site</u> includes the lands and facilities where the activity takes place and upon which it is usually dependent. River recreation activities generally depend heavily upon site characteristics. Modification of such things as stream flow variables modifies the site's ability to attract and support activity purposes, and it changes the ability of the site and of the activity to deliver psychological outcomes.

(4) The <u>activity attributes</u> are the characteristics of the activity purpose which enable it to perform the functions which provide psychological outcomes. If site changes are to be evaluated, the activities must be described in terms of their relative capability to serve the psychological outcomes. Description of the relationships, if any, between these activity attributes and site variables will allow impacts to be traced.

(5) <u>Site variables</u> are the conditions and circumstances of the site which affect its suitability and attractiveness for various activity purposes. For river recreation they include stream flow variables as well as many other things. The activity for which the site is used has site performance requirements. Some of these relate directly to the psychological outcomes which the activity is expected to deliver. Considerable work has been done to try to describe the site performance requirements of various activities (Hyra, 1978; Chubb, 1976; deBettencourt, 1979; Andrews, et al.,

1976). Very little work has been done to explain the process by which site variables affect recreation.

(6) The personal variables are those individual traits which affect recreation behavior. They include such things as age, income, sex, ethnicity, stage in the life cycle, education, occupation, personality, etc. Such variables modify motives, preferences, and choices in recreation and help to explain the richness of variation in recreation behavior that exists among people.

(7) Situational variables include such things as the relative proximity of the site and the recreation demand, the type, efficiency and cost of transport linkages, intervening opportunities, etc. To some extent these variables may modify the impact of stream flow changes on recreation. They certainly intervene strongly in the overall demand process.

(8) Market segments are categories into which individuals are grouped in order to simplify the problem of dealing with interpersonal differences. Such grouping may be done in terms of social or institutional categories such as income, ethnicity or geographic area. Ideally, market segments are based on behavioral homogeneity, with people of similar recreational behavior being grouped together. Different market segments may respond differently to stream flow changes.

In a behavioral demand model these categories of variables are linked together by means of mathematical equations which explain the complex interrelationships. Knowledge of these relationships would also allow the specific impacts on recreation of environmental changes to be predicted for different activities and market segments. The state-of-the-art here is very primitive, however, and this somewhat superficial exposure of the various elements of recreation behavior is presented only as a paradigm which will serve as a framework for raising questions about the proposed stream flow methodology, as well as for guiding constructive improvement.

Key concepts include the following:

(1) Recreation behavior is complex, voluntary, and discretionary, suggesting that it may be quite sensitive in sometimes unexpected ways to environmental change.

(2) Response of recreationists to stream flow may vary by activity and by market segment.

(3) Some impacts may be more important than others, depending upon the market segments and psychological outcomes affected.

(4) Impact on psychological outcomes may occur without obvious changes in manifest behavior.

(5) The state-of-the-art of explaining relationships between environmental conditions and recreation behavior and benefit is primitive. While hydraulic measurement and simulation may be well developed in terms of proven theories and standard methods and measures, prediction of recreation behavior is not.

QUESTIONS AND CRITICISMS OF THE CIFSG METHODOLOGY AND RESEARCH NEEDS

The purpose of this section is to list the questions and criticisms that have grown out of our deliberations about the CIFSG methodology. These questions and criticisms define needs for further research. In some cases what is needed is simply more rigorous definition and conceptual clarification. In other cases we may have a need for theoretical development. But, there are some questions which can only be answered through expensive and time-consuming empirical research, and there may be state-of-the-art problems where we aren't even sure what the question is.

In reflecting on these questions, the concept of cost-effectiveness should be kept "up front." We could spend millions of dollars here, and we need to assess the value of correct answers, and the cost of accepting less precise answers. The research could be attacked at several levels, with judgment, common sense and conventional wisdom being the least expensive and most immediate. However, it is essential to establish a much more rigorous conceptual framework for the problem before going further with empirical or methodological research. In the hope of urging this along, we offer in the Appendix constructive suggestions and examples of what needs to be done.

The Scope of the Mission

On face value it appears that the CIFSG has taken as its mission to develop methods for assessing the impacts of changes in depth and velocity on certain instream recreation activities, with predictions of depth and velocity being derived from hydraulic simulation and representative reach sampling. This, we believe, is too narrow. Is it the product of a deliberate decision to begin with manageable pieces of the puzzle with the intent to broaden out as problems get solved? Or, is it nearsightedness or infatuation with pet tools and convenient methods? What are the practical questions the group is trying to answer, and will their approach lead to answers to important questions?

The Structure of Recreation

It is obvious that different recreation activities have different relationships to stream flow, and it is likely that for different types of people, there may be different relationships to streamflow, even for a given activity. The CIFSG has not given adequate attention to those questions. It makes sense to develop methodology in terms of a few important activities that are convenient to work with. But, to predict impact on recreation potential, it will be necessary to develop and test the methods in terms of all recreation activities that are significantly linked to instream flow. It will also be necessary to understand how person types and personal variables intervene, or activity specification will be incomplete and it will not be possible to give proper attention to the social distribution of costs and benefits.

Stream Flow Variables

Depth and velocity are important to many forms of stream-related recreation, but they are obviously not the only important variables. It is natural that the group has begun with depth and velocity, because it follows directly from prior work on fish habitat, and it is the language of the hydraulic simulation approach being used. However, there is real danger that the work on recreation may be going down a long and technical trail which could lead nowhere.

The overall structure of the recreation problem faced by CIFSG needs further clarification. What variables are important to which activities for what kinds of people? Given the overall structure, the value of working with depth and velocity can be assessed and next steps in the research can be rationally selected.

Criterion Methodology

The criterion methodology being used is the "probability of use" function. The following specific questions and criticisms must be addressed before the work proceeds:

(1) Is probability a useful criterion and is it the best way to go?

(2) If so, probability of what? Probability of "use" is dangerous, because it mixes recreation potential with recreation demand and profoundly complicates the problem.

(3) The basis for the functions at present is apparently to glean minimum, maximum, and optimum conditions of depth and velocity from available literature or by common sense judgment and then to assume (a) probability is proportional to desirability, (b) probability is zero at minimum and maximum limits and one at the optimal condition, and (c) between these points desirability and probability vary linearly.

The assumption that probability is proportional to desirability is a dangerous and fallacious assumption which implies some misleading things. However, until there is a rigorous definition of the event whose probability is discussed, nothing can be done. If probability is what is wanted, and if the event can be rigorously defined, then the assumptions, derivations, and implications can be explored properly. It will then also be possible to begin rigorous exploration of relationships between the probability of this event and the magnitude of stream flow variables. The way the methodology is now constructed, true probabilities do not exist and it is not known what event is being predicted.

(4) It is incorrect to multiply the "probabilities" to obtain the "composite probabilities." Apparently the multiplicative approach stems from some incorrect assumptions and loose definitions.

(5) Existing literature may be an inadequate source of information upon which to base the criteria. Complementary sources are certainly needed, and original basic research may be required.

Hydraulic Simulation

Hydraulic simulation is simply a way to describe and predict the hydraulic conditions of a river, based on sample measurements at representative reaches. Regarding the application to the recreation problem, the following concerns need to be addressed:

(1) Can hydraulic simulation produce the kinds of information needed for recreation analysis in language appropriate to recreation? Does recreation need the kind of information hydraulic simulation can produce? Can the "gestalts" and details that are meaningful to recreation be adequately represented?

(2) For what activities and under what conditions is the method useful and cost-effective? Under what conditions is it invalid or inefficient?

(3) How should rivers be classified or segmented to make the method appropriate?

(4) Is a combined strategy required, using critical reach in some places and representative reach in others?

(5) What other options are available and have they been adequately identified and evaluated? Is hydraulic simulation being used simply because it is something the CIFSG knows how to use, has

found useful for the fish habitat problem, and wants to see used? For example, might recreation analysis be better served through stream descriptions produced by experienced recreationists who know the streams, together with judgmental criteria about their appropriateness for different users?

(6) What other relevant hydraulic parameters might be developed and simulated? For example, can parameters be theoretically or empirically derived to describe the power, scale, and regularity of hydraulic phenomena such as standing waves, backrollers, etc.?

The Weighted Unit Area (WUA) Concept

WUA has come under criticism partly because of inadequate clarification of what it is, and partly because of incorrect interpretation by the CIFSG. The following are important concerns:

(1) What is WUA? Does probability times area have any conceptual meaning? This question has been neglected.

(2) It is invalid to imply that WUA can be used to measure equivalence or substitutability of streams or sections of streams, without first specifying exactly what WUA means so that we understand what about the streams is equivalent or substitutable. To say that two streams with equal WUA are equally desirable is to presume that WUA is proportional to desirability. This is a fallacy on two counts: (a) it is based on the unjustified assumption that probability is proportional to desirability; and (b) it fails to recognize that WUA is an expected value and as such is strictly limited in what it means. These failures lead to the unfortunate trap where 100 junk yards are concluded to be substitutable for one rose garden. Under very specialized conditions,

the interpretation may be correct, such as the example of 100 acres of poor pasture being capable of providing the same quantity of nutrient for cows as 10 acres of good pasture. With recreation, however, we may be dealing with a different kind of process, and the analogy may not be valid.

(3) Are there other methods that might be used instead of or in addition to WUA that will allow more effective comparison and evaluation? For example, might it be more meaningful to use a centile profile to summarize the data so that the disaggregate richness is preserved, rather than using an aggregate average where the same "average" can be produced by many drastically different situations. The use of average measures alone exposes one to the "statistical deer hunting trip" in which a high miss and a low miss bags the deer on the grounds that the average is the same as for two hits.

(4) How is resource carrying capacity related to WUA if at all? The CIFSG methodology seems to imply that WUA is somehow a measure of capacity. This is not valid, although WUA may be related to capacity.

<u>Scope of Relevance</u>

In addition to the questions outlined above, we are concerned that the CIFSG methodology does not include sufficient concern for social welfare values. It certainly is important to look at the relationship between stream flow variables and the suitability of the site for use by individuals for recreational purposes. This is a major part of the question. However, an important and neglected part of this question is how to include the distribution of that suitability for use across different individuals and social classes. Too many quantitative decision criteria, e.g., cost-benefit ratio and willingness-to-pay are used in ways which are blind to the distribution of costs and benefits. Policy is not and should not be blind to distributional questions, and this should be considered by the CIFSG.

Another related deficiency is that we have seen no way for the methodology to include "collective" or "policy" values that may not be included in personal choices. For example, historic preservation, natural conservation, endangered species protection, and protection of options for the future are collective concerns that may not be reflected in private decisions.

CONCLUSION

The purpose of this workshop was to critique the progress to date of the CIFSG methodology of assessing instream flows for recreation. The method they have developed has many strengths and many weaknesses, which have been pointed out. One of the weaknesses, the failure to tackle the whole problem, is because the problem is larger than the CIFSG mission. We have attempted to organize the definition of the whole problem, and have defined the problem which, in the author's opinion, will permit the group to more fully understand how the portion of the problem they are wrestling with fits into the big picture. We have taken a close look at the CIFSG problem, mission, and methodology and have added some needed background on recreation behavior. In the Appendix which follows, which is authored by Dr. George Peterson, there is a more detailed discussion of some of the theoretical and conceptual concepts that were mentioned in the paper.

APPENDIX A

to

The Relationships Between Recreation and Instream Flow

by

George L. Peterson

TOWARD CONCEPTUAL CLARIFICATION

Stream Flow

The primary stream flow concept, as derived from the mission of the CIFSG and the policy concerns that created that mission, is the quantity of water flowing in the stream channel. The primary stream flow variables are therefore Q, the volume of water per unit time flowing through a transect and dQ/dt, the rate at which the quantity of flow is changing. For most practical questions it may be possible to confine the analysis to steady-state conditions in which $dQ/dt = 0$.

The policy question is one of economically efficient and equitable allocation of water among competing uses or needs. With regard to recreation, the basic question is, what is the relationship between (a) the recreation potential of the stream, and (b) the amount of water flowing in the stream. Ideally we would like to be able to (1) evaluate the recreation potential of a given stream or stream reach under natural conditions of stream flow, (2) evaluate the change in recreation potential that would be caused by specific changes in the amount of water flowing in the stream, and (3) specify the amount of flow required to support specified levels of recreation potential. In each of these questions it should be recognized that "recreation" must be defined in terms of specific activities.

In addition to the parameter Q, there may be other variables to which recreation potential is sensitive and which are of concern to recreation in the context of the stream flow problem because (1) they measure primary consequences or corollary conditions of stream flow volume (e.g., stage, depth, velocity, etc.); (2) they measure secondary consequences of stream flow volume (e.g., turbidity, physical channel and stream bank conditions, instream vegetation, fish population and behavior, water quality, etc.); or

(3) because they intervene to modify the relationship between recreation potential and stream flow variables (e.g., water quality, climate, gradient and other physical channel characteristics, location and accessibility, etc.).

The problem here is to define stream flow and its corollary, consequent, and intervening conditions in terms of the meaning for recreation potential. Without a model or theory of the processes by which recreation potential is sensitive to stream flow, it is not possible to be sure that (1) the important variables have been specified, and (2) they have been defined in a meaningful and operational way.

Recreation

In a previous section recreation was defined in general terms as voluntary play behavior. However, the very complex and diverse reasons why people do things which we tend to regard as recreation, and the great diversity of forms taken by recreation lead to the conclusion that while general definitions are of philosophical interest, they are of little practical value.

Before we can deal rigorously with recreation potential and the relationship to stream flow, we need to identify the recreation "species" that are of interest. This is a two-sided problem. On the one hand is the need for an appropriate taxonomy of activities. This includes identification of those kinds of activities which are of interest to the stream flow question, as well as an understanding of the scale or level of detail with which activity types need to be specified. On the other hand is a need for an appropriate taxonomy of people and/or human situations. The meaning of stream flow conditions for a given kind of recreation may depend on who we are talking about and what the personal circumstances are at the time.

It is also useful to identify several levels of recreational dependence upon stream flow. At the primary level are activities which occur in or on the water flowing in the stream (e.g., swimming, boating, wading, fishing, etc.). At the secondary level are activities which are dependent on or enhanced by the presence of the stream but which do not occur in or on the water (e.g., sightseeing, photography, camping, picknicking, bird watching, hunting, etc.). At the tertiary level are those activities which occur in the vicinity of streams, either by coincidence or because of the presence of facilities, but which are relatively independent of stream flow conditions. As a first step it is reasonable to narrow the scope of the problem to the primary level and deal only with the activities which occur in or on the water. It must be recognized, however, that it is an incomplete first step. Camping and picknicking for example may be very sensitive to changes in stream flow, because the opportunity for water sports makes a campground or picnic area more attractive to a broader spectrum of people.

Recreation Potential

Assuming that the taxonomies of recreation activities and persons are available, "recreation potential" will now be defined in rigorous terms. There may be several different ways to define the concept. Here, we will use probability and the concept of "suitability for use" as the basis for the definition. The purpose is to offer a rigorous definition by way of proposition and illustration. It will be up to the researchers to refine and/or revise the approach.

The Theoretical Definition: Let it be assumed that the set of all people of type h who have decided or will decide to engage in activity j can be identified. Let each of these persons be in the condition of being at home and having decided to do activity j. Let them be placed with their choice of equipment and accompaniment and at no cost in time, money, effort or inconvenience for transportation at location ℓ on a stream under specific conditions of stream flow. At this time let there be no access to, or awareness of, substitute locations for the activity or to substitute activities. Let the person then decide whether or not to engage in activity j at location ℓ. A decision not to engage in the activity at that location causes the person to be returned home again at no cost. A decision to engage in activity j at location ℓ exposes the person to whatever risk, cost, effort, inconvenience or other consequences are associated with the doing of the activity at that location, except that upon completion of the activity the return trip home is costless. Indecision is taken to be a decision not to engage in the activity.

By way of further clarification it must be understood that location ℓ is a specified point on, in, or adjacent to the river. It is not a region or locale. For example, the point may be the middle of a wide stream where the water is ten feet deep and the velocity of the water is 15 ft/sec. This point is obviously unsuited for wading and few if any people would decide to do this activity at that point. Although there may be large areas nearby where the water is one foot deep and virtually motionless, we have defined this to be irrelevant to the decision regarding the specific location in question.

Let $N_{hj\ell}$ (Accept) be the number of people of type h who accept location ℓ as a place to do activity j. Let $N_{hj\ell}$ (Reject) be the number of people who decide not to do the activity. Now define the "Probability that the site is acceptable" as

$$P_{hj\ell}\text{ (Accept)} = \frac{N_{hj\ell}\text{(Accept)}}{N_{hj\ell}\text{(Accept)} + N_{hj\ell}\text{(Reject)}} \qquad (1).$$

This probability is one way to define recreation potential. Simply stated, it is the likelihood that a point is acceptable for a given activity independent of any effects of competing sites, competing activities, or access costs.

P(Accept) is an indirect measure of recreational quality although the probability is likely to be a monotonic function of quality. In theory there is for each individual a utility function in which the magnitude of utility (satisfaction) derived from the site varies with stream flow parameters. However, while such individual utility functions may be measurable in theory, they are not measurable in practice, at least not at reasonable cost. Even if they could be measured, they cannot be aggregated into group utility functions without making invalid political and numerical presumptions. However, the P(Accept) concept can be rigorously derived from utility theory with the assumption that there is in the personal utility function a threshold isoquant dividing the unacceptable stream flow conditions from those which are acceptable. The threshold utility functions are measurable and they can be aggregated probabilistically. This approach to the derivation of P (Accept) is known as Utility Threshold Theory (deBettencourt and Peterson, 1977; deBettencourt, 1979).

For linear activities such as rafting, canoeing, kayaking, motorboating, jet boating, etc., the hypothetical "experiment" which defines recreation potential must be defined in terms of a specified reach of a stream, rather than at a point. The subject would be placed at an assigned point of initiation of the activity and would be assigned a point of completion. The activity would then take place throughout a defined reach. The evaluation is of the entire reach, not of a point. If the subject accepts the reach, he must accept all consequences and risks associated with the activity throughout the entire reach. If the reach or point being evaluated is inaccessible due, for example, to high cliffs or lack of roads, these conditions apply only while the activity is in progress. The problem of getting to and from the stream at the points of initiation and conclusion is irrelevant to recreation potential, though it is not irrelevant to the actualization of the potential.

In between the point activities and the reach activities are those which do not require a lengthy reach, but which have no meaning at an isolated point. There is no joy in wading or swimming at an isolated point. Thus, there is need for further refinement of the point concept to include the need for sufficient linkage or proximity to other acceptable points.

It is absolutely necessary to isolate any definition of recreation potential from the morass of actual recreation participation and demand. Actual demand is concerned with the sensitivity of actual use to various conditions of (1) resource quality at the site, (2) proximity of the site to population, (3) magnitude of accessible population, (4) quality and quantity of transportation facilities, (5) population awareness of the resource, and (6) existence, location and quality of competing sites, etc. Demand and participation include but are vastly more complex than recreation potential. Ultimately we may want to assess impacts of changes in stream flow on recreation demand, but at this time it is better to begin with the question of impact on recreation potential or "site quality."

<u>A Practical Definition</u>: The theoretical definition of recreation potential developed above is not very practical. While the theoretical probability thus defined may exist, it cannot be measured by means of the hypothetical "experiment" used to define it. A practical procedure is needed whereby the probability can be estimated. Two strategies are available.

An empirical or inductive strategy would estimate the probability from observations of behavior. Because of the need to control demand-related variables, laboratory experiments or questionnaire methods will have to be used unless a procedure can be devised to isolate the effects of site quality variables in actual recreation site choices. At present this is beyond the state-of-the-art. For an example of questionnaire procedures which simulate site choice see deBettencourt, 1979; and Peterson, et al, 1973. Also, the work of Kenneth Hammond (University of Colorado, 1976) on Human Judgment and Social Interaction utilizes computer graphics techniques which may be highly effective for extracting P(Accept) functions from representative individuals.

A deductive strategy would construct a theoretical explanation of the probability (as a function of stream flow variables from known principles of human behavior). This is also beyond the state-of-the-art at this time. Research on this line would have to be aimed at developing and refining the principles of human behavior.

The Criterion Function Concept

In the previous section we implied, but did not make explicit, the concept of a criterion function for recreation potential. Assume that there are four sets or classes of variables to which recreation potential at a stream is sensitive. Let the first set be the primary and corollary conditions of stream flow such as Q (rate of flow), H (stage), D (depth), V (velocity) and any others that may be important. To simplify the notation let these variables be Q_1,-------Q_n. Let each variable be defined at a point, ℓ, such that the primary variables are $Q_{1\ell}$, $Q_{2\ell}$,----$Q_{n\ell}$.

Let the second set of variables be those which help to determine recreation potential and which are also dependent to some extent upon the primary stream flow conditions. That is, when the amount of water in the stream changes, these variables (e.g., turbidity stream bank conditions) change. Let them be separable in the function, i.e., they do not intervene in the relationship between potential and the primary variables. Call these variables

$$X_{1\ell}, X_{2\ell}, \text{-----------------}, X_{m\ell}.$$

Let the third set of variables be those which help to determine recreation potential, but which are independent of stream flow conditions and of the relationship between potential and stream flow. In other words, they are independent and separable from the primary stream flow variables (e.g., forest type, developed facilities, wildlife, etc.). Call these variables

$$Y_{1\ell}, Y_{2\ell}, \text{-----------------}, Y_{p\ell}.$$

Let the fourth set of variables be those which intervene in the relationship between recreation potential and any or all of the other variables. For example, variables describing the physical characteristics of the stream channel will certainly modify the effect of Q on recreation potential. A rough channel or a circuitous channel may become dangerous under some flow conditions while a smooth, straight channel may not. These variables may or may not be independent of the other variables. Call these interveners

$$Z_{1\ell}, Z_{2\ell}, \text{-----------------}, Z_{q\ell}.$$

Now define the criterion function which determines and measures recreation potential at a point. To simplify notation, we will use vector notation, where X, for example, represents the set of all X's.

$$P_{hj\ell}\ (\text{Accept}) = F_h\ (Q,Z) + g_h\ (X,Z) + K_h\ (Y,Z) \qquad (2)$$

where f_h, g_h and K_h are functions which are separable from each other. It should be recalled that we have defined Y to be independent of Q and, consequently, also of X. We have defined X to be dependent upon Q.

Equation (2) is a criterion function by which $P_{hj\ell}$ might be evaluated, given values for Q,X,Y, and Z, if the functions f, g, and k could be specified. The reasons for this somewhat complicated formulation will become clear in subsequent sections.

Recreation Requirements for Stream Flow

Given a definition of recreation potential as in equation (1) and a definition of a criterion function as in equation (2), we are now in a position to define "recreation requirements for stream flow." For simplicity of illustration, assume that the recreation activity in question is sensitive only to depth (D) and velocity (V), both primary stream flow variables, and that there are no X, Y, or Z variables in the criterion function. This simplified function can be represented as

$$P_{hj\ell}(\text{Accept}) = f_h(D_\ell, V_\ell). \qquad (3)$$

If depth and velocity were the only variables of concern for swimming, then the function for person type h might be as in Figure A-1. For wading it might be as in Figure A-2. These functions are shown graphically as isoquants or centiles of constant probability. The meaning of the shaded area will be explained shortly.

Now it is necessary to introduce the concept of "policy standard" as a basis for defining "recreation requirements." Here it is assumed that the policy question of distribution of benefits among individuals or classes of individuals can be dealt with adequately by means of the classification h. In other words, there are no distributional concerns within class h, only

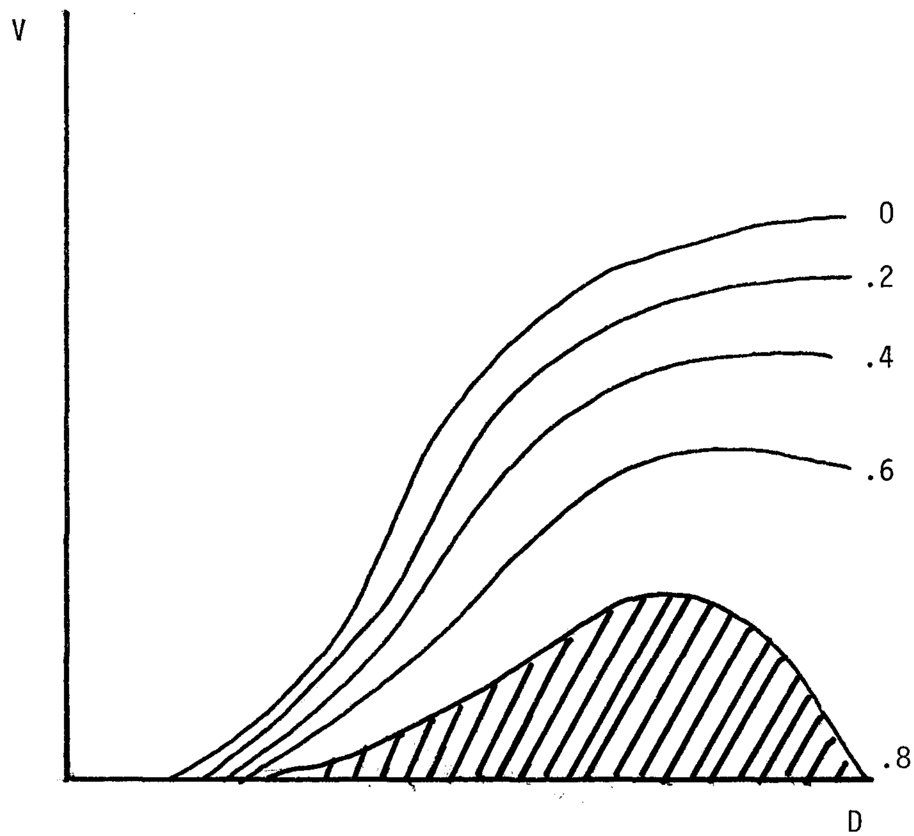

Figure A-1

$P_{h\ell}$(Accept) = f_h (Depth, Velocity) for Swimming
(Hypothetical relationship under the assumption that depth and velocity are the only two variables of concern).

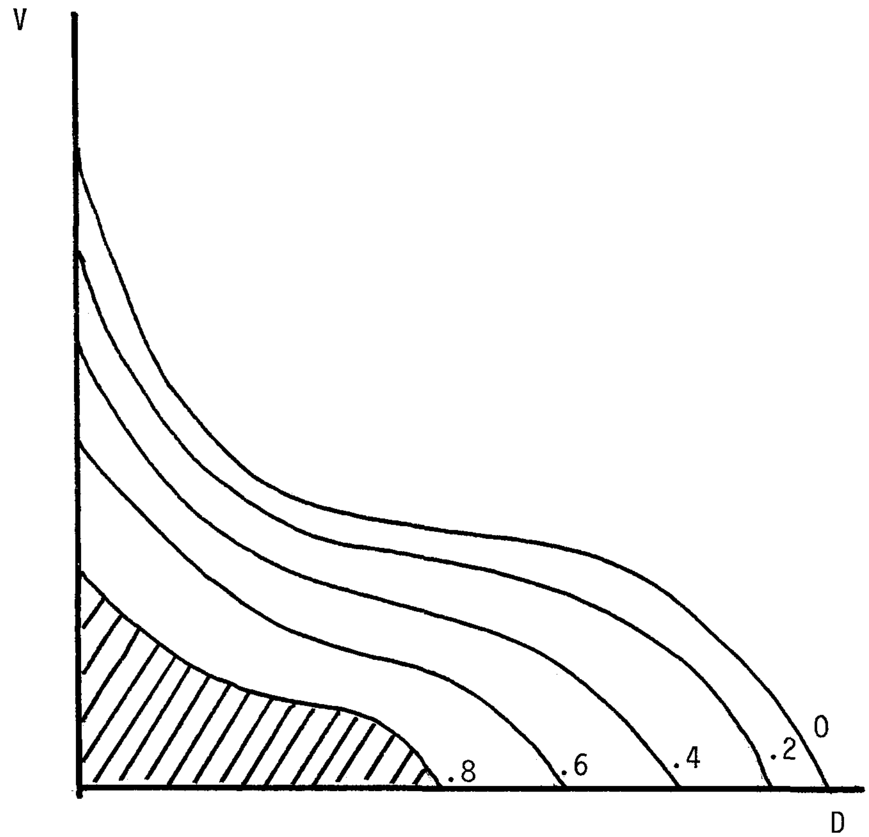

Figure A-2

$P_{h\ell}$(Accept) = F_h(Depth, Velocity for Wading)

(Hypothetical relationship under the assumption that depth and velocity are the only two variables of concern).

between classes. Otherwise, a more elaborate formulation will be required.

Assume that the policy process has decided that for class h a location on a stream is of "adequate" recreation quality for a given activity if it is acceptable to 80 percent of the individuals in the group. (This is not unreasonable, because a similar concept of "voting" is used to decide whether a political candidate is acceptable.) However, if the group h is improperly constructed, this process may cause systematic discrimination against particular members of the class, say children or handicapped. If the classes are properly constructed in terms of similarities and differences between individual utility threshold functions, such systematic discrimination will not occur.

The shaded area in Figures A-1 and A-2 represent the combinations of depth and velocity which are acceptable to 80 percent or more of the members of class h. With an 80 percent policy, the requirements for each activity are that the joint occurrence of depth and velocity must be above the .80 centile on the criterion function. To judge whether the stream flow conditions of a specific stream at a particular location satisfy the requirements for recreation, it is thus necessary to have (1) the criterion function for each activity and person type of concern, and (2) a policy standard (e.g., ≥80 percent) for each activity and person type. The magnitudes of the stream flow variables are then entered into the criterion function and the magnitude (or change in magnitude) of $P_{hj\ell}$(Accept) is calculated and tested against the policy standard.

<u>The Impact on Recreation of Changes in Stream Flow</u>

A change in one of the variables in equation (2) will cause a change in P(Accept) if the criterion function has been correctly specified. A change in P(Accept) may cause a change in recreational use of the site.

Changes in the recreational use of the site will cause changes in the site, changes in the users themselves, and changes in the economy. The "impact" on recreation of a change in stream flow is thus a complicated matter, even if concern is limited only to the significant changes. Clearly the mission of the CIFSG should aim toward the development of capability to evaluate this total impact on (or through) recreation caused by a change in the amount of water in a stream.

However, it makes sense to start with a first step, rather than expecting the group to make the whole trip all at once. While it is true that a brick house cannot be built only with bricks, it is also true that it cannot be built without them. The first step, then, is to concern ourselves only with the impact of stream flow changes on recreation potential, P(Accept). In other words, if we change a primary stream flow variable (an element of the set Q, say volume of flow, or stage or velocity, or depth, etc.), what is the associated change in site quality as measured by $P_{hj\ell}$(Accept)?

For the sake of simplicity in illustration let us again assume that depth (D) and Velocity (V) are the only two variables to which P(Accept) is sensitive. The criterion function then reduces to equation (3). There are two important questions that must be addressed before the question of impact can be answered:

(1) Is there interaction between D and V in their relationship with P(Accept)? That is, are their effects on P(Accept) separable?

(2) Is the magnitude of D independent of the magnitude of V?

For example, a simple function in which the effects of D and V are separable is

$$P(\text{Accept}) = \alpha_{hj} V_{\ell} + \beta_{hj} D\ell, \tag{4}$$

where α_{hj} and β_{hj} are coefficients that are specific to the activity and type of person but which are constant from site and from stream to stream. In this equation the effect on P of a change in V is independent of the magnitude of D. The impacts thus appear to be separable and we need only to assess the partial relationship between P and V in order to assess the impact of a change in V. In other words, no matter what value D takes, the impact of a change in V is the same. Mathematically, we can say

$$\frac{d\,P}{d\,V} = \alpha. \tag{5}$$

In fact, this may not be true. In view of question (2) above, the total derivative of P with respect to V (in equation 4) is

$$\frac{d\,P}{d\,V} = \alpha + \beta\,\frac{d\,D}{d\,V}\,. \tag{6}$$

Equation (5) is true if and only if

$$\frac{d\,D}{d\,V} = 0, \tag{7}$$

or in other words, if D is independent of V.
The effects of V and D are still separable but they are not independent if equation (7) is not true. Figure A-3 shows the path analysis for impact when equation (7) is true or not true.

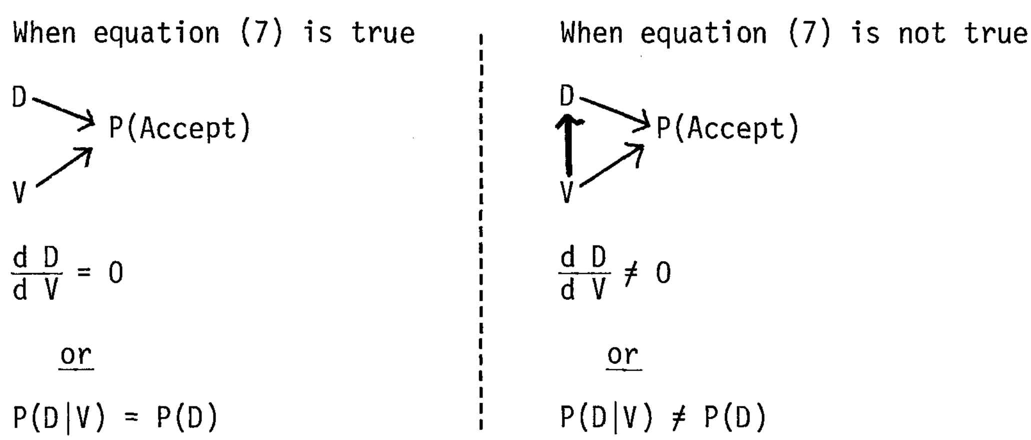

Figure A-3
Path Analysis for Equation (7)

If the relationships are stochastic, equation (7) would be written

$$P(D|V) = P(D). \tag{8}$$

In words, this says that the probability of D, given V is equal to the probability of D, i.e., the probability that depth has the magnitude D is independent of the magnitude of velocity.

An example of a functional form in which interaction is present is

$$P(\text{Accept}) = \alpha \; D \; V. \tag{9}$$

The subscripts h, j, and ℓ have been dropped to simplify the expression. Of course more conditions would have to be specified for equations (4) and (9) in order for them to define true probabilities. The sensitivity of P to a change in V is given by

$$\frac{d\ P}{d\ V} = \alpha \left[D + V \frac{dD}{dv} \right]. \tag{10}$$

If dD/dV = 0, the derivative reduces to

$$\frac{d\ P}{d\ V} = \alpha \; D. \tag{11}$$

This says that the rate of change of P with respect to a change in V depends on the magnitude of D.

The points demonstrated by this somewhat involved journey through simple equations are

(1) If there is interaction between two of the variables to which recreation potential is sensitive, it is impossible to know the impact of a change in one variable without knowing the magnitude of the other variable.

(2) If recreation potential is sensitive to two variables which are functionally interdependent, it is impossible to know the impact on recreation potential of a change in one without understanding also the impact on the other variable.

These conclusions mean that if we desire to assess the impact on recreation potential of a change in a stream flow variable, say V, then it is absolutely necessary to have complete specification of those parts of the criterion function which involve interaction or interdependence with V. Other parts of the criterion function can be ignored, because they are separable from and independent of V. While such other factors may indeed change, such changes are irrelevant to the impact of a change in V. It is impossible, however, to assess the impact of a change in V unless all of those variables to which P(Accept) is sensitive and which interact or are interdependent with V are included in the analysis and their parts of the criterion function are completely specified. Depending on the nature of the interrelationships, the criterion function may thus have to be a set of simultaneous equations describing a causal network.

However, while this may be true and necessary in theory, it may or may not be important in practice. As always, there is the practical need to separate the significant from the insignificant. Many of the relationships may be of lesser orders of magnitude and thus negligible - but this must be learned, not taken for granted.

In practice it may be possible to measure P(Accept) directly, either in real situations or in controlled experimental settings and, through statistical techniques, separate the significant relationships from those which are negligible. Statistical techniques suitable for estimating such relationships include, among others, analysis of variance and covariance, and discriminant analysis. But, they require the observation of P(Accept) under a meaningful variation of key variables, and they require stratification with respect to interactive variables, with separate analysis within strata.

To point out that there may indeed be problems of interaction and interdependence in assessing the impacts of changes in stream flow conditions consider the following:

(1) The quantity of flow, stage, velocity, depth, turbulence, and who knows what other stream flow variables are all important to the recreation potential for various activities and person types. But, they are strongly interdependent. As an example, the depth and velocity of water flowing through a wier (i.e., a critical reach) are hydraulically interrelated.

(2) Depth and velocity interact in their relationship with recreation potential, at least for some activities. With wading, for example, a velocity of 10 ft/sec is clearly more acceptable when the depth is three inches than when the depth is two feet. A depth of two feet may be acceptable, however, when the velocity is zero.

(3) Class IV and V on the International scale of whitewater difficulty may be more acceptable to experienced kayakers on an accessible stream where rescue is readily available than in a remote and inaccessible gorge, where a dunking would necessitate a perilous swim for several miles through dangerous white water and a long and perhaps impossible hike out.

(4) Class II and III white water on the same scale as above is clearly more acceptable to open canoeists when the water is warm than when it is cold.

Assessment of Recreation Potential

From proceeding sections, recreation potential is the magnitude of $P_{hj\ell}$(Accept). For an activity that can occur at a point, it is the magnitude of the probability at a given point. For a linear activity, it is the magnitude of the probability for a specified reach of the stream. For an activity that requires an area, it is the magnitude of the probability for a specified section of the stream and/or adjoining lands. Recreation potential thus is assessed by evaluating the magnitude of $P_{hj\ell}$(Accept) for a point, reach, or section of stream. This is a simple matter if the criterion function (equation 2) is completely specified. It may be impossible if the function is not completely specified.

However, if we are evaluating several points on the same stream, then many of the variables in equation (2) may change very little from point to point. Likewise, in evaluating several similarly situated streams, many variables may change very little from stream to stream. In such cases it may be possible to evaluate differences in recreation potential, knowing only those parts of equation (2) which pertain to a few key variables which change significantly. It may also be that if equation (2) were completely known, there may be some variables to which P(Accept) is very sensitive and others to which P(Accept) is much less sensitive. In such a case the less sensitive variables will cause only relatively small and insignificant changes in P(Accept) even though the changes in the variables themselves may be great. Such effects may be negligible, and it is often possible to work with functions which are incompletely specified in terms only of those variables which change strongly from situation to situation and which have a very sensitive relationship with P(Accept). Such incomplete functions can often be obtained by empirical means without having a complete theoretical framework. However, they should be based on a rich range of variation, and they must not be generalized beyond the range of circumstances represented by the data.

To illustrate these concepts, consider again the simple relationship given by equation (4). Let it be assumed that the coefficients have been estimated empirically as

$$P = 0.05Q - 0.00001\,Y \qquad (12)$$

with adequate constraints on Q and Y to disallow values of P outside the range from 0 to 1. A change of one unit in Q will be 5000 times as important as a change of one unit in Y. Even if Y is dependent on Q, it can be ignored as long as the units of measurement and ranges of variation for the two variables are roughly equivalent. However, if Q is measured in kilometers and Y is measured in millimeters and the ranges of variation are the same, then P is 100 times more sensitive to Y than to Q. If, however, Q and Y are both measured in the same units and have the same variance, and if Y were unknown and thus ignored in the empirical analysis (i.e., incomplete specification), we would find that the function containing only Q would explain 99.98 percent of the variance of P. In other words, with good experimental design which randomizes the effects of unknown and unspecified variables under actual conditions, the unexplained portion of the variance of P is a measure of the relative sensitivity of P to the unspecified variables. For example, if 98 percent of the variance of P is explained by three conveniently specified variables, then recreation potential can be evaluated with reasonable confidence, using only those variables. But, if depth, velocity and turbidity explain only 5 percent of the variance of P, recreation potential cannot be evaluated with any confidence. Changes and differences in recreation potential can be evaluated if it can be assumed that the unknown and unspecified variables remain constant. However, this may be a very dangerous assumption. In any case, such empirically estimated criterion functions should never be generalized beyond the kinds of situations contained in the set of empirical observations.

In summary this line of reasoning suggests that when complete specification of the criterion function is not possible, it is reasonable to measure P(Accept) and the predictor variables of interest under a wide range of conditions, then estimate a plausible functional relationship and evaluate the completeness of specification. As a result, one's confidence in using the relationship to assess recreation potential, by means of the proportion of the variance of P that has been explained, is increased.

Functions (either mathematical, tabular, or graphical) which are based on conditional observations of the relationship between P and some other variable, say V, are of unknown value in assessing recreation potential. By "conditional" observation, we mean observations under the condition (or assumption) that all other variables are held constant. They may be used to assess partial impact if the estimation is indeed under controlled conditions and the application is under the same controlled conditions. However, where two variables are interdependent, and interactive, say for example a depth and velocity which interact and which may have a hydraulic interrelationship in a critical reach, it is nonsense to develop a partial relationship for the one variable under the assumption that the other remains constant. In such cases, the naturally possible joint occurrences <u>must</u> be evaluated.

<u>A Closer Look at the Use and Misuse of Multiplicative Probability Models</u>

In Hyra (1978) as in other documents produced by the CIFSG, it is assumed that separate and independent P(Accept) functions can be obtained for each instream flow variable of concern, in particular depth and velocity. The probabilities thus defined are then multiplied to obtain the "composite" P(Accept) function, i.e., the joint probability that the site is acceptable given the joint conditions of depth and velocity. This approach implies some things about the probabilities which in turn imply some things about the human decision process.

The rule from probability theory that is apparently being used is

$$P(A \cap B) = P(A)P(B). \tag{13}$$

This rule says that the probability of the intersection of the occurrence of event A and the occurrence of event B (i.e., that both event A and event B will occur) is equal to the product of the probability that event A will occur multiplied by the probability that event B will occur. In fact this is a special case of a more general rule:

$$P(A \cap B) = P(A)P(B|A) \tag{14}$$

where P(B/A) is the conditional probability that event B will occur, given that event A occurs. If event A and event B are independent, then

$$P(B|A) = P(B) \tag{15}$$

and equation (13) is true.

Thus, the CIFSG approach assumes that acceptance of velocity (event A) and acceptance of depth (event B) are independent events. Assuming that depth and velocity are the only two variables of concern, this implies that the person who judges the suitability of a site for a given activity looks <u>only</u> at velocity and decides whether to accept it. It also implies that he independently looks <u>only</u> at depth, with absolutely no regard for what he has decided (or will decide) about velocity, and decides whether to accept depth. Given a group of individuals who behave in such a fashion, it would then be correct to say

$$P(\text{Accept D and V}) = P(\text{Accept V}).P(\text{Accept D}). \tag{16}$$

We must now ask whether it is possible to obtain P(Accept V) and P(Accept D) such that they are independent events. Consider an experiment in which a person desiring to do an activity, say wader-fishing, is told that a site has a depth of four feet and is asked to accept or reject the depth. His answer will be, "It depends on what the velocity is." If, without specifying depth, we were to ask if he would accept a velocity of 3 ft/sec, he would say, "It depends on what the depth is." If we were to specify that the depth is four feet and ask if he would accept a velocity of 3 ft/sec, he would be likely to say, "No." If we specify that the depth is one foot and ask if he would accept a velocity of 3 ft/sec, he would be likely to say "Yes" (assuming that acceptable conditions of fish species, size, habitat, and catch habits are also present in all cases).

This says that (in some cases at least) it may be nonsense to ask the separate questions about depth and velocity, because the consequences on the person and the two variables are not separable. When the question is asked to accept or reject velocity, in fact the question being asked is to accept or reject the consequences of velocity. But those consequences of velocity are not separable from the consequences of depth. Thus, to present the questions separately is to ask unanswerable questions. One is willing and able to answer questions only about the joint occurrence of depth and velocity -- and, there may be many more variables as implied by the definition of equation (2) for which the consequences on the person are not separable.

However, if depth and velocity are the only two variables, the question can be asked about different velocities, given that depth is specified, and vice versa. If such jointly specified questions are answerable, then two types of P(Accept) functions could be derived for velocity: (1) conditional curves where P(Accept) = $f_D(V)$ is different for each specified value of D, and (2) a projected distribution function where D is randomized and shows up as "error" or unexplained variance in P(Accept) = f(V). Figure A-4 shows a hypothetical situation in which D interacts with P(Accept) = $f_D(V)$ but is not correlated with V.

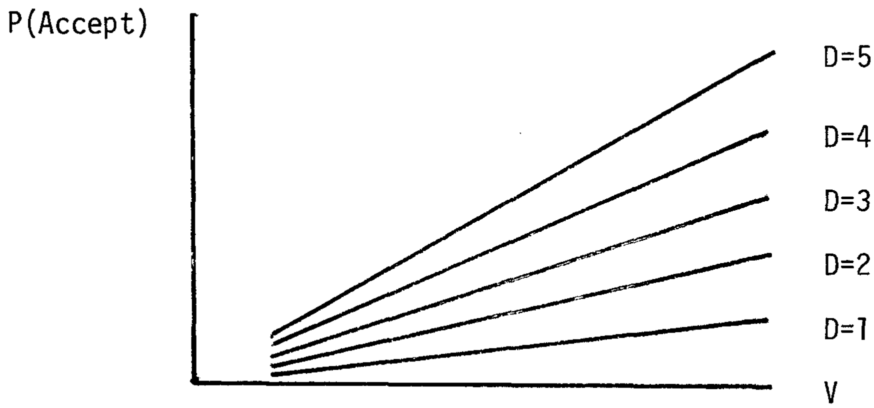

Figure A-4
$P(Accept) = f_D(V)$
Interaction but no correlation
between D and V.

In fact D and V may be hydraulically related in nature as well as interactive in the decision process. This means that some combinations of depth and velocity are more likely than others. Figure A-5 shows $P(Accept) = f_D(V)$ in which D and V interact in the decision process and are correlated in nature. (3)

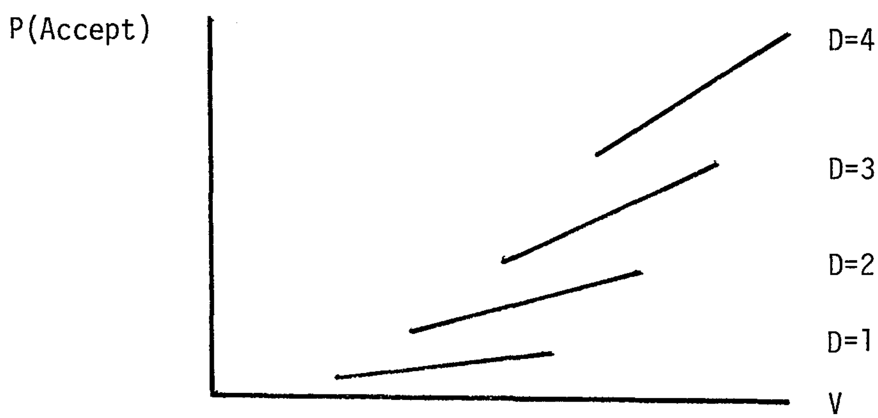

Figure A-5
$P(Accept) = f_D(V)$
Interaction and Correlation between D and V

Figure A-6 shows a projected distribution function for the relationship between P(Accept) and V in which the effects of D have been randomized. (2) Correlation and/or interaction may be present. The

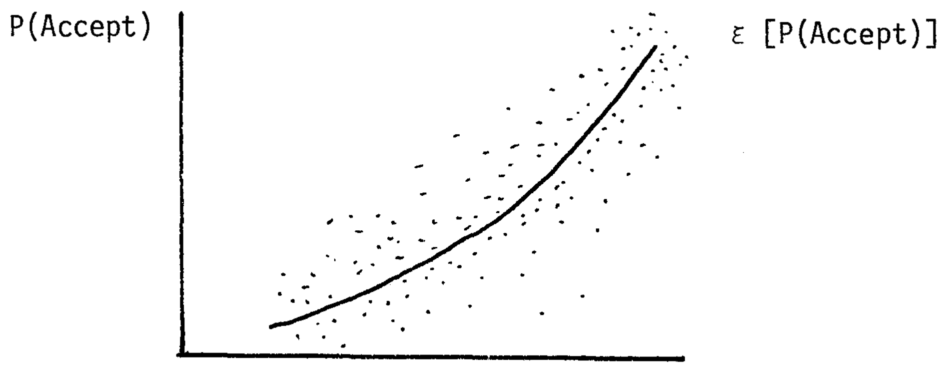

Figure A-6
P(Accept) as a function
of V with D randomized

function is actually a joint probability density function of a probability. The line representing the relationship is the locus of $\varepsilon\,[P(\text{Accept})|V]$ with D (and all other effects) randomized. The proportion of the variance of P(Accept) explained by $\varepsilon[P(\text{Accept})|V]$ is R^2 (or η^2 in a non-linear case) and is a measure of the ability of variations in V to explain variations in P(Accept) when all other important variables are left out of the function and randomized.

Presumably, such a function could be estimated for $\varepsilon\,[P(\text{Accept})|D]$. Is it then reasonable to say that

$$\varepsilon[P(\text{Accept})\ DNV] = \varepsilon[P(\text{Accept})\ V] \cdot \varepsilon[P(\text{Accept})\ D]? \qquad (16)$$

We think that this is an invalid and misleading concept.

The conclusion is apparently that for those variables which interact in their effect on P(Accept), the only way the question can be defined is as a <u>joint occurrence</u>. The questions are not separable either in the functional relationship (equation (2)) or in terms of probabilities.

From the point of view of strict probability theory, it is not correct to regard P(Accept) as a random variable as in Figure A-6 and equation (16). For any given value of D, there is an unique value of P(Accept). Likewise for any given value of V, there is an unique value of P(Accept). For simplicity assume that depth is a discrete variable and may take only the values

$$D_1,\ D_2,\ \ldots\ldots,\ D_i,\ldots\ldots\ldots,D_m. \tag{17}$$

These values are mutually exclusive; that is, it is not possible for two depths to exist simultaneously at the point in question. Let velocity also be discrete and mutually exclusive with the values

$$V_1,\ V_2,\ \ldots\ldots,\ V_j,\ldots\ldots,V_n. \tag{18}$$

We are interested in the occurrence of three random events: (1) the occurrence of "Accept," i.e., that the point in the stream is judged to be acceptable for a given activity; (2) the occurrence of the depth D_i at the point; and (3) the occurrence of V_j at the point.

Given that the depth at the point is D_i, the probability that the site is acceptable is

$$\begin{aligned} P[\text{Accept}|D_i] = {} & P[(\text{Accept}\ |V_1)|D_i] \cdot P[V_1|D_i] + \\ & P[(\text{Accept}|V_2)|D_i] \cdot P[V_2|D_i] + \ldots\ldots\ldots\ldots + \\ & P[(\text{Accept}|V_n)|D_i] \cdot P[V_n|D_i], \text{ or} \end{aligned} \tag{19}$$

$$P[\text{Accept}|D_i] = \sum_{j=1}^{n} P[(\text{Accept}|V_j)|D_i] \cdot P[V_j|D_i]. \tag{20}$$

Likewise, there is a single value of P(Accept), given each value of V_j:

$$P[\text{Accept}|V_j] = \sum_{i=1}^{m} P[(\text{Accept}|D_i|V_j] \cdot P[D_i|V_j]. \tag{21}$$

These equations can also be written as follows:

$$P[\text{Accept}|D_i] = \sum_{j=1}^{n} P[\text{Accept}|V_j \cap D_i] \cdot P[V_j|D_i] \tag{22}$$

$$P[\text{Accept}|V_j] = \sum_{i=1}^{m} P[\text{Accept}|D_i \cap V_j] \cdot P[D_i|V_j]. \tag{23}$$

This shows that in order to calculate either $P[\text{Accept}|V_j]$ or or $P[\text{Accept}|D_i]$ we must know $P[\text{Accept}|V_j \cap D_i]$ for all i and j. Thus

$$P[\text{Accept}|D_i] \cdot P[\text{Accept}|V_j] = \text{nonsense} \tag{24}$$

and

$$\text{Nonsense} \neq P[\text{Accept}|V_j \cap D_i] \tag{25}$$

The formulas

$$P(AB) = P(A) \cdot P(B|A) \tag{26}$$

and

$$P(AB) = P(A) \cdot P(B) \text{ if } P(B) = P(B|A) \tag{27}$$

are valid when A and B are different events. Equation (27) is true when they are independent events. But $P(\text{Accept}|D_i)$ and $P(\text{Accept}|V_j)$ are not independent events. Indeed they are the <u>same event</u> under different conditions.

The conclusion is the same whether we look at the problem in terms of the decision process (equation 2) or in terms of probability theory (equation 22 and 23):

$P[\text{Accept}|D_i \cap V_i]$ must be observed directly.

The multiplicative fallacy has arisen because of the way the events were defined in the first place. For example, independent and reasonable questions can be asked: (1) what is the probability that you will eat brussels sprouts, if offered them; and (2) what is the probability that you will accept a bright green shirt, if offered one? The probability that you will accept both, if offered both, is simply the product of the two probabilities (assuming that the decisions are independent). Now consider three very different questions. (1) What is the probability that you will come to dinner if <u>required</u> to eat brussels sprouts? (2) What is the probability that you will come to dinner if <u>required</u> to wear a bright green shirt? (3) What is the probability that you will come to dinner if required to wear a bright green shirt <u>and</u> eat brussels sprouts? The event here is "coming to dinner," and the probability of that event occurring is being examined under different conditions which influence the decision.

It is clearly the latter problem we are dealing with, not the former.

<u>Methodology for Evaluating and Comparing Streams</u>

Assuming that the obstacles to definition and measurement of P(Accept) under the various conditions on which it is dependent can be overcome, the recreation potential of a stream consists of a matrix $P_{hj\ell}$(Accept), or, given the person type and activity, the recreation potential consists of a vector of discrete probabilities, P_{ℓ}(Accept), one for each location being evaluated. Unfortunately this "information" is not very "informative." We can look at a point and say how good it is and we can compare and rank order points, but we have no way to combine these discrete pieces of information into an evaluation of the quality of the overall stream, and there is no way to compare different streams. A frequency distribution can be compiled showing the number of points or units of surface area on the stream at each level of probability. A centile profile could thus be calculated and the centile profiles could be compared between streams. A centile profile shows, as with I.Q. or aptitude tests, the proportion of the points (persons tested) having scores at or below the score in question. Two streams could be compared as in Figure A-7.

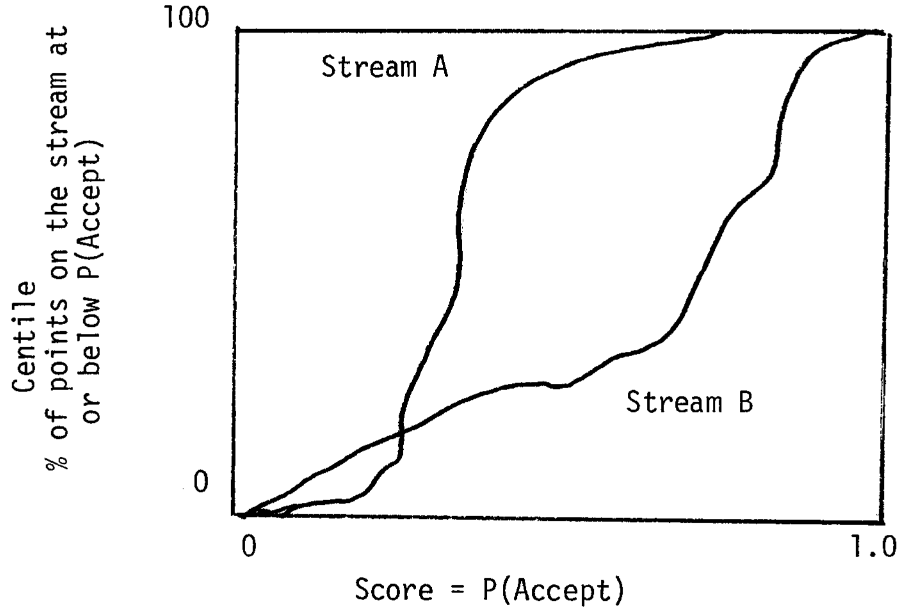

Figure A-7
Centile Profile Comparison
of Two Streams

The CIFSG methodology bypasses the centile profile concept and goes one step further to advocate calculation of "weighted unit area." If A_i is the number of square feet of surface area with P(Accept) = P_i, then

$$WUA = \sum_{i=1}^{n} P_i A_i, \tag{28}$$

where n is the number of discrete categories into which probability has been aggregated. The WUA measure is interpreted as being the equivalent surface area at a probability of 1.0.

This has come under considerable criticism, mainly on the grounds that it implies that one hundred junk yards are equivalent to one rose garden. In fact the concept of WUA as calculated has a valid meaning. The problem is with the interpretation that has been placed upon it.

Assume that a stream has been completely divided up by a grid onto m squares of unit area. Let P_i(Accept) be measured for each of the unit area squares. Now define

$$\text{WUA} = \sum_{i=1}^{m} P_i(\text{Accept})\ (A_i)$$

$$= \sum_{i=1}^{m} P_i(\text{Accept})\ (1) = \sum_{i=1}^{m} P_i(\text{Accept}). \tag{29}$$

Assume that P_i(Accept) is measured by means of an experiment in which N people are asked to accept or reject each square. Let the number accepting each square be n_1, n_2, ...n_m. By definition,

$$P_i(\text{Accept}) = \frac{n_i}{N}\ , \tag{30}$$

and

$$\text{WUA} = \frac{n_1}{N} + \frac{n_2}{N} + \frac{n_3}{N} + \ldots + \frac{n_m}{N}$$

$$= \sum_{i=1}^{m} \frac{n_i}{N} = \frac{1}{N} \sum_{i=1}^{m} n_i \tag{31}$$

Thus, WUA is the total number of acceptable judgments divided by the number of judges, or the average number of times a judge makes an acceptable judgment. Therefore, <u>WUA is simply the average or expected number of acceptable units of area, given the P_i(Accept) profile over all units of area</u>. If one stream has a WUA of 5 and another has a WUA of 10, we can say that on the average people would judge the second stream to have twice as much usable area as the first. This does not necessarily imply, however, that two streams with WUA = 5 are substitutable for one stream with WUA = 10.

It does not even mean that the two streams with WUA = 5 are substitutable for each other. Nor does it mean that a WUA of 10 is better than a WUA of 5. WUA is no more nor less than an estimate of the expected value or average of the number of units of area that would be judged to be acceptable in the long run if many people were to judge every unit of area. As such it suffers from all the deficiencies of "expected value" when used as an evaluation criterion.

For example, consider three investment opportunities. Option A has a probability of 0.99 that a net return of $10,000 will be realized and a probability of 0.01 that a net loss of $900,000 will be suffered. Option B has a probability of 0.90 that a net return of $101,000 will be realized and a probability of 0.10 that a net loss of $1,000,000 will be suffered. Option C has a probability of 1.00 that a net return of $900 will be received.

These are summarized in Table A-1.

Option	Net Return if successful	Probability of Success	Net Loss if failure	Probability of failure	Expected Value
A	$10,000	0.99	$900,000	0.01	$900
B	$101,000	0.9	$900,000	0.10	$900
C	$ 900	1.0	--	0.00	$900

Table A-1

Comparison of three different investment opportunities with the same expected value

All three options have an expected value of $900, yet they may be non-equivalent to some investors. If we are to "play the game" over and over again many times, the three options produce the same net result - an average winning of $900 per play. For a one-shot game, however, a conservative small business would go for the sure $900, while a big conglomerate with many "games" and a huge capital reserve might prefer option B.

Thus, as an expected value, WUA measures how much adequate stream area there is on the average over the population as a whole, but it cannot be applied validly to individual evaluations. Furthermore, it is blind to the distribution of wins and losses within the population, unless this is accounted for by segmentation by person type. Finally, the concepts of P(Accept) and WUA are based on the criterion of "adequacy," not optimality. There is absolutely no reason to assume that the "value in use" of the site (i.e., the personal utility gained from using the site) is proportional to the probability that it will be judged to be acceptable. Herein lies the dilemma that 100 junkyards are not equivalent to one rose garden. While it may be true that a unit area rose garden will be judged acceptable 100 percent of the time and a unit area junkyard will be judged to be acceptable one percent of the time, the "value in use" of the rose garden may be 1,000,000 times as great as the value in use of the junkyard, and there may be a less desirable rose garden, which is also acceptable 100 percent of the time, but which delivers "value in use" only 1000 times as great as the junkyard. Thus, WUA is grossly incomplete for recreation assessments and cannot be used to measure "value in use" (i.e., nothing can be said about equivalence or substitutability) unless "value in use" is strictly proportional to P(Accept).

<u>Capacity, Recreation Potential and WUA</u>

In this section we ask whether any information about the recreational capacity of a site can be derived from P(Accept) or WUA. By recreational capacity we mean the <u>carrying capacity</u> of the site, i.e., the quantity per unit of recreation activity the site can support. There are two components to the carrying capacity question: (1) ecological capacity; and (2) social capacity. Ecological capacity is the maximum quantity of activity that can be put on the site without unacceptable damage to the site. Social capacity is the maximum quantity of activity that can be put on the site without unacceptable damage to the quality of the user's experience. Obviously, there are second order relationships, i.e., damage to the site may reduce user satisfaction, so the two kinds of capacity are not clearly separable in concept. However, in practice, there are usually environmental policy concerns which define ecological capacity. Social capacity is usually concerned with the first order effects of congestion - mutual interference among users.

Ecological capacity may be related to WUA. WUA is the average number of units of area that will be judged to be acceptable, when a person judges every unit of area. Thus, it can be viewed as the average "size" of the resource that is available for use, or the area over which use is likely to be spread. However, some specific units of area, those with large values for P(Accept), will be accepted much more frequently than others, and thus they will be used much more heavily. Also, some units of area will have much greater value in use than other units of area. Even though two unit areas may be judged acceptable by a person, the one with the greatest value in use will be chosen for use. If, independent of WUA, a policy decision can be made for the ecological capacity of each unit of area, and if this policy can be enforced through rationing or price rationing, then WUA may be a reasonable estimate of the number of units of area available. The expected number of units of capacity available requires the additional information about the capacity of each unit of area.

Let C_i be the ecological capacity as established by policy for the i^{th} unit area of a stream. Let P_i(Accept) be the probability that the unit area is acceptable. Because each unit area has an area of one, WUA is

$$WUA = \sum_{i=1}^{n} P_i(\text{Accept})\ A_j$$

$$= \sum_{i=1}^{n} P_i(\text{Accept}). \tag{28}$$

Now define WCA as "weighted capacity area:"

$$WCA = \sum_{i=1}^{n} P_i(\text{Accept})\ A_i\ C_i \tag{29}$$

WCA is the expected or average number of units of capacity that will be judged to be acceptable each time a person judges <u>every</u> unit of area. While this quantity may be useful, it is an "expected value" and suffers from the weaknesses of expected value and is blind to distributional concerns unless appropriately segmented by social type.

Social capacity is a much more complex question. It must be defined from the users' subjective point of view. Given sufficient understanding of each user's decision criteria, it might be possible to "figure out" S_i, the social capacity of each unit of area, and to establish S_i as a policy. The limiting capacity is then either C_i or S_i, whichever is less.

There may be a productive way to define S_i using the concept of P (Accept). For simplicity assume that we are talking about the social capacity of a room at a cocktail party. Assume that the probability that a person will enter the room or remain there is P, and that P is a function of the number of people in the room. This defines a simple stochastic process with three states as in Figure A-7.

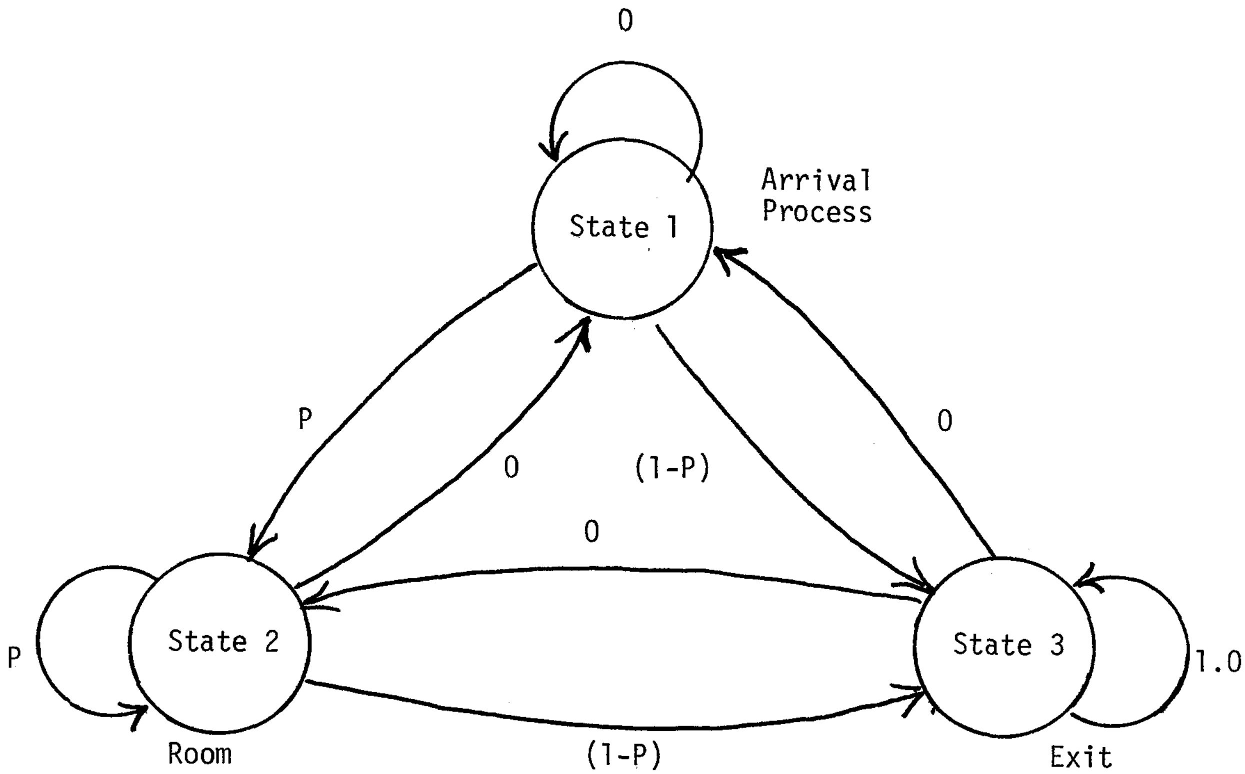

Figure A-7

Simple Social Carrying Capacity Model

State 1 is the arrival process which delivers people to the entrance to the room. State 2 is the room. State 3 is an absorbing exit into which people go and from which they do not return once they have decided to leave or not to enter State 2, the room. The matrix of probabilities is

$$P = \begin{bmatrix} 0 & P & (1-P) \\ 0 & P & (1-P) \\ 0 & 0 & 1 \end{bmatrix} \tag{30}$$

If the arrival process is some stationary process which delivers a uniform flow of people to the door of the room and if P decays as the population of the room increases, there will be some steady-state population of the room to which the system will stabilize. If P is P_i(Accept) and the "room" is a unit of area of a recreation resource, then the steady state population might be regarded as a definition of social carrying capacity. This "capacity," however, may depend on the nature of the arrival process and may not necessarily maximize total value in use. To maximize value in use we need commensurate individual utility functions.

The same model might be expanded to describe a site with several different kinds of users. Assume that P(Accept) for each type of user is some function, perhaps unique to user type, of the number of each type of user at the site. Presumably there will be a steady-state population for each type of user, depending on each arrival process and on the way P (Accept) changes with the population profile at the site.

Given several sites, this model could also be developed into a displacement process describing the invasion and succession that takes place when some change in the site changes the P(Accept) function of user types or when the arrival process changes.

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PROBLEMS FOR RESEARCH

Introduction

This section summarizes research problems which have been identified by the four modules participating in the IFG workshop on Instream Flow Criteria and Modeling. The research problems identified are interdisciplinary in nature cutting across module subject areas. The following research problems are not presented according to module subjects but grouped according to general concerns including: input data (sources and reliability), instream flow needs assessment methodologies, and decision frameworks.

Input Data

As with any approach which depends on both emperical data and existing baseline data resources the IFG methodology could be vastly improved if either funding were provided for collection of new data, or data resources were found which allow direct application of the methodology. Since this is not the case, a review of problems with input data may be useful.

Lack of short-term and continuous streamflow forecasts in many areas increase the risk to water managers in making proper adjustments in storage releases to meet continuous instream flow requirements. Possibilities exist for changes in streamflow management without interference with legal water rights. What is needed is a method of forecasting water releases on a daily basis during critical seasons. Data must provide a basis for determination of regional differences in hydrological conditions (e.g. west vs east).

Extensive and expensive field data collection is necessary in order to predict hydraulic habitat parameters. This limits the number of projections which can be made while there is a need for projections spanning a wide range of flows (e.g. low flow to flood stage).

The effect of sediment load and characteristics on effective pollutant load are unknown. This prevents accurate assessment of water quality at instream habitat locations of interest. Research is needed on the physical-chemical relationships between sediment and pollutants in the stream.

Generally, sources of specific pollutants in streams are unknown. As a result, accurate predictions of pollutant loading under various runoff scenarios cannot be made. Technology is needed for identifying potential non-point sources of pollutants on various classes of watersheds in various geographic areas, and linkage is needed between pollutant yield and both runoff and sediment yield.

There is incomplete understanding of the relationships of stream primary production to instream flow. Although it is possible from existing data to reliably predict benthic production, data on allochthonous production is limited and available mainly for low order streams.

Aquatic insect production as a function of habitat conditions is poorly understood. Therefore, it is impossible to predict the aquatic insect food supply component of the habitat. Research is needed to establish the relationships between habitat parameters and aquatic insect production.

Sufficient factual data are lacking on fisheries responses, including behavior and mortality, under various combinations of water quality and physical microhabitat. Although some criteria for minimum and optimum habitat are available (ref. U.S.E.P.A. Quality Criteria for Water - 1976), for the most part that data is incomplete. There is a need for research to determine dose response relationships which reduce the ability of aquatic organisms to function.

The seasonal and geographic differences for behavior of most fish species under given habitat conditions are unknown. This represents a serious constraint to the application of habitat criteria. What is needed is a clear definition and refinement of "probability of use" curves for fish species at all life stages by season and geographic region.

There is a lack of factual data on fish biomass production (standing crop) under various habitat conditions. Therefore, criteria for habitat suitability are incomplete. Further, the economic effects of habitat conditions cannot be quantified. What is needed are field observations of standing crop compared to habitat conditions over a wide range of habitat parameters.

Along the same lines the degree of flexibility in habitat rejection by fish is unknown. This is a serious gap in formulating comprehensive criteria for habitat suitability. Research is needed on fish behavior responses to a wide range and many combinations of habitat variables. This is true also for primary and secondary production in the stream. Factors considered should include physical, chemical, and biological parameters.

Instream Flow Methodologies

When considering a methodology for instream flow assessment the pre-requisites include sufficient input data and a reasonably clear understanding of how the output will be used. The methodology can then either be extremely simple depending on minimal data resources or range through various levels of complexity dependent on better or more comprehensive data. The existing IFG methodology attempts to use emperically collected and existing data, unfortunately this data is incorporated in the methodology at different levels of precision. Recognizing that predictive tools for environmental assessment and habitat projections must be comprehensive even if they are less than perfect leads to the conclusion that more than one methodology should be available. The different methodologies might represent a tiered approach dependent on data availability and decision requirements. The first tier should included a simplified methodology suitable for the purpose of habitat projections which do not require extensive field data.

The other tiers which are dependent on more sophisticated data or decision making procedures can develop from the existing methodology. The following represent improvements to the existing methodology which would significantly improve reliability.

A prediction of habitat changes due to changes in streamflow should represent a substantial length of stream segment. There is uncertainty whether or not this is accomplished by the IFG method. There is need for criteria to be established for field study site selection that will yield representative habitat conditions.

The capability to predict transient channel geometry and bed-particle size distribtuion during and following unsteady sediment-water discharge is required for many streams, particularly large rivers. Habitat conditions under variable discharge cannot be predicted with present state-of-the-art models. Modeling capability is needed for relating microhabitat channel geometry and bed particle size distribtuion to flow parameters as a function of time in unsteady flow. This should include moveable bed characteristics which can be correlated with habitat bed requirements.

The present state-of-the-art does not permit adequate projections of flow and geometric characteristics in natural streams. Precision of estimates of hydraulic variables in natural streams is low. There is need for projections which incorporate some measure of frequency. Low level remote sensing technology should be considered for data acquisition.

There is a lack of appropriate methods of water quality projection. Consequently, the habitat projection method is unable to incorporate water quality parameters directly. Available water quality models should be tested to determine their suitability for the IFG model. Promising models should be adapted to the IFG model.

The technology does not exist for estimating non-point pollutant yield to streams from the watershed as a function of land management and land use practices. Consequently, water quality cannot be predicted for instream habitat purposes. There is need for pollutant yield modules for various watersheds, land use and management, and runoff combinations.

There is an absence of food chain variables in habitat prediction models. For example, the relation between habitat suitability for benthic invertebrates and habitat suitability for target fish species is unknown. Three particular needs are: (1) an evaluation of chemical and physical parameters in combinations which define certain limits (lethal, survival, acceptable, optimum) for various species and life stages of benthic invertebrates which can be compared with habitat suitability for target fish species; (2) the impact on a fishery due to given loss of invertebrate population is needed; and (3) how invertebrate functional groups - collectors, gatherers, scrapers, and grazers - respond to given habitat conditions and in turn impact on target fish. Since the same implications of primary (algae and allochthonous materials) to secondary (aquatic insects) consumers should be noted, methodologies must be improved to predict ecosystem responses to changes in flow.

In summary the selection of appropriate methodology to be applied in predicting hydraulic habitat conditions is often a problem due to constraints and limitations of specific methods. Consequently, less than satisfactory predictions of flow parameters, stream geometry and water quality on natural streams are being made. There is a need for a classification system differentiating watershed-stream systems which can be coupled with decision requirements. Such a system would identify the tier, its accuracy and provide an estimate of probable costs. Such a system would be an integral part of IFG use.

Decision Framework

The use of the IFG methodology is dependent on the needs and requirements of managers and decisionmakers. If the methodology falls short of meeting their requirements then it will not be used. At all times the question "How will the results be used" must be kept in mind. Since the reliability and versitility of the IFG habitat projection method is not fully established, there is a lack of confidence and acceptance by potential users. At the outset it should be clearly understood that the acceptance of the methodology will be based on how well it meets the requirements of users. At present the IFG methodology has found only limited application but is being tested throughout the United States. Even before the results of these tests are in it is possible to identify major decision problems.

There is incomplete understanding of minimum acceptable instream habitat conditions. Although in many cases the possibility of stream management improvement exists, lack of well-established criteria for different levels particularly minimum levels of habitat suitability is a deterrent to management changes. Improved information is needed for survival and lethal limits on all critical habitat parameters.

There is a lack of knowledge of river system operational strategies which would optimize habitat conditions. Instream flow regulations to preserve aquatic cosystem habitats are therefore not generally accomplished. Models for river system management which are applicable to various important hydrologic systems are needed.

In summary, it appears that a decision framework based on a tiered methodology is possible. Methodologies which efficiently use data and fiscal resources will improve utility and decisionmaking.

Summary

There is an urgent need to continue the exchange of new advances among the several disciplines in order to expedite the eventual formulation of fully suitable models. Further, the research emphasis should be upon developing comprehensive models which include all necessary and sufficient parameters (e.g. hydraulic parameters are necessary to specification of fish habitats, but they are not sufficient). Once these models are produced, a decision framework must be available to assure their use. Since clear requirements for present use exist, the existing IFG methodology should review its high dependence on "experience" in using empirical relations for projecting instream flow needs.

IFG Response to Workshop

Since the conclusion of the workshop, a number of changes in the incremental methodology have been made by the Cooperative Instream Flow Service Group in response to the various suggestions made by the participants. The workshop was viewed by the IFG as a learning tool and a great deal was learned. Some changes were made immediately following the workshop, others have been implemented during the past year, and others are still in the planning stages. The following statements highlight a number of the ways in which the Instream Flow Group has benefited from the workshop.

1. Critiques forcefully demonstrate that the IFG must be much more careful in defining terminology associated with the methodology. For example, the IFG Incremental Methodology was based on "probability-of-use-curves." Mathematically, the curves are treated as marginal probability functions; however, workshop participants pointed out that these curves do not truly represent probabilities. It is one thing to handle the curves mathematically as probability functions, yet quite another to assume, or imply, that they are actual probabilities. Consequently, the IFG is using the term criteria curves rather than probability-of-use-curves to avoid confusing or misleading users of the methodology.

2. The IFG has greatly altered its approach to introducing the methodology to new audiences. In the workshop, participants were given a cursory review of the methodology and were set to work to provide their critique. A great deal of misunderstanding ensued because most workshop participants were not familiar with the historical need for such a methodology, the decision context

in which the methodology is intended to be used, or the scientific logic on which the methodology is based. The numerous misunderstandings that surfaced during workshop discussions had a great impact on IFG's subsequent training approaches. Currently, a substantial portion of any training session is spent on describing the historical need for an "incremental" methodology; the type of uses envisioned for the methodology; the types of uses that are inappropriate for the methodology; how the methodology relates to prevailing schools of thought in fishery science; and the assumptions that must be made in order to apply the methodology correctly. Furthermore, all of these concerns are reiterated throughout the training setting, along with detailed descriptions of the application techniques. Thus, while the expected outcome of the workshop was to focus on the internal logic of the methodology, we learned a great deal about the process of communicating.

3. Prior to the workshop, the focus was primarily on hydraulic simulation and the Habitat model. These are but analytical tools within the context of an overall methodology. Subsequently, the Instream Flow Group has placed a great deal more emphasis on the entire procedure (methodology) for evaluating instream impacts. A modular approach is being emphasised to provide users with a structured format for consciously evaluating the significance and stability of such components as watershed processes, water chemistry, and food web relationships <u>before</u> application of any computer model.

In addition guidelines and procedures are being developed to assist users in determining whether or not their intended application and particular field situation is consistent with the assumptions of the methodology and its related computer models. The workshop discussions clearly demonstrated a need for a structured procedure to evaluate underpinning assumptions as part of the methodology itself.

4. Workshop participants identified the need for further validation and verification of the various models and assumptions under a variety of circumstances to strengthen the basic internal logic and to expand application of the methodology. Such activities are programmed in the Instream Flow Group budget for Fy 80. Validation studies are programmed which will test the relationship between weighted usable area and standing crop. Sensitivity analysis will be conducted to determine the kinds of precision necessary (the risk of error) for each of several input variables. The intent of the sensitivity analysis is to make explicity the internal attributes of the model.

5. We learned from the water quality module that many water quality models are presently available and that water quality can most generally be assessed on a macrohabitat basis. As a result, our emphasis will focus on interpretation of water chemistry parameters with respect to aquatic habitat, rather than on additional water quality modeling.

6. We learned that we had inadequately described the IFG Incremental Methodology. At the time of the workshop, a series of information papers were available which dealt with different aspects of the methodology (such as how fish criteria curves are derived) but there was no single description of the methodology. The chapter in this report by E. Woody Trihey is but one attempt in that direction. It describes what the methodology is, what it does, and how it should be used. Other reports on the methodology that are currently

being developed also contain this kind of information to serve as a point of contact and to communicate to the reader the methodology that is being described. Had such a single, brief description been available at the time of the workshop, participants could have come to the workshop much better equipped to provide a focused, systematic evaluation.

7. The Instream Flow Group has learned that it is not adequate simply to identify assumptions. Users are better served by testing whether the assumptions can normally be justified and whether inaccurate assumptions really make a difference. As examples, a) the assumption of independence -- Utilizing the best data available, a procedure was developed (ref. Module III) to test for independence among variables. Grenney and Voos found that while some dependence is present, it is not so significant as to result in a serious error in the final model output for most applications. This analysis is presented in the forthcoming paper, Estimation of Parameters for the Incremental Methodology. b) the assumption of linearity -- Recently the assumption of a linear relationship between biomass and weighted usable area has been examined in the western states of Oregon, Wyoming, and Colorado. A strong positive linear correlation has been found for salmonids. It was also determined that no linear relationships could be identified between weighted usable area and density for aquatic insects. A curvilinear relationship existed in all cases examined which as yet cannot be generalized. c) the assumption of channel stability -- The Instream Flow Group has recently contracted for a workshop on sediment transport and channel change. This workshop will build upon discussions originating in the November 1979 workshop reported on in these proceedings. The new workshop will bring together a number of experts on sediment transport modeling to identify the most

promising avenues of pursuit for analyzing stream channel hydraulics on a microhabitat basis in unstable channels.

8. As a result of the discussions within the recreation module, it became apparent that a separate analytical approach needs to be developed. Instream flow requirements for many instream recreation pursuits could better be evaluated on a macro basis (large stream reach) rather than the site-specific microhabitat approach used for fishery assessments. Although this has yet to be initiated, the final results will probably be quite similar to suggestions by James W. Scott in his letter commenting on the review draft of the recreation model report.