Instream Flows for Recreation: A Handbook on Concepts and Research Methods

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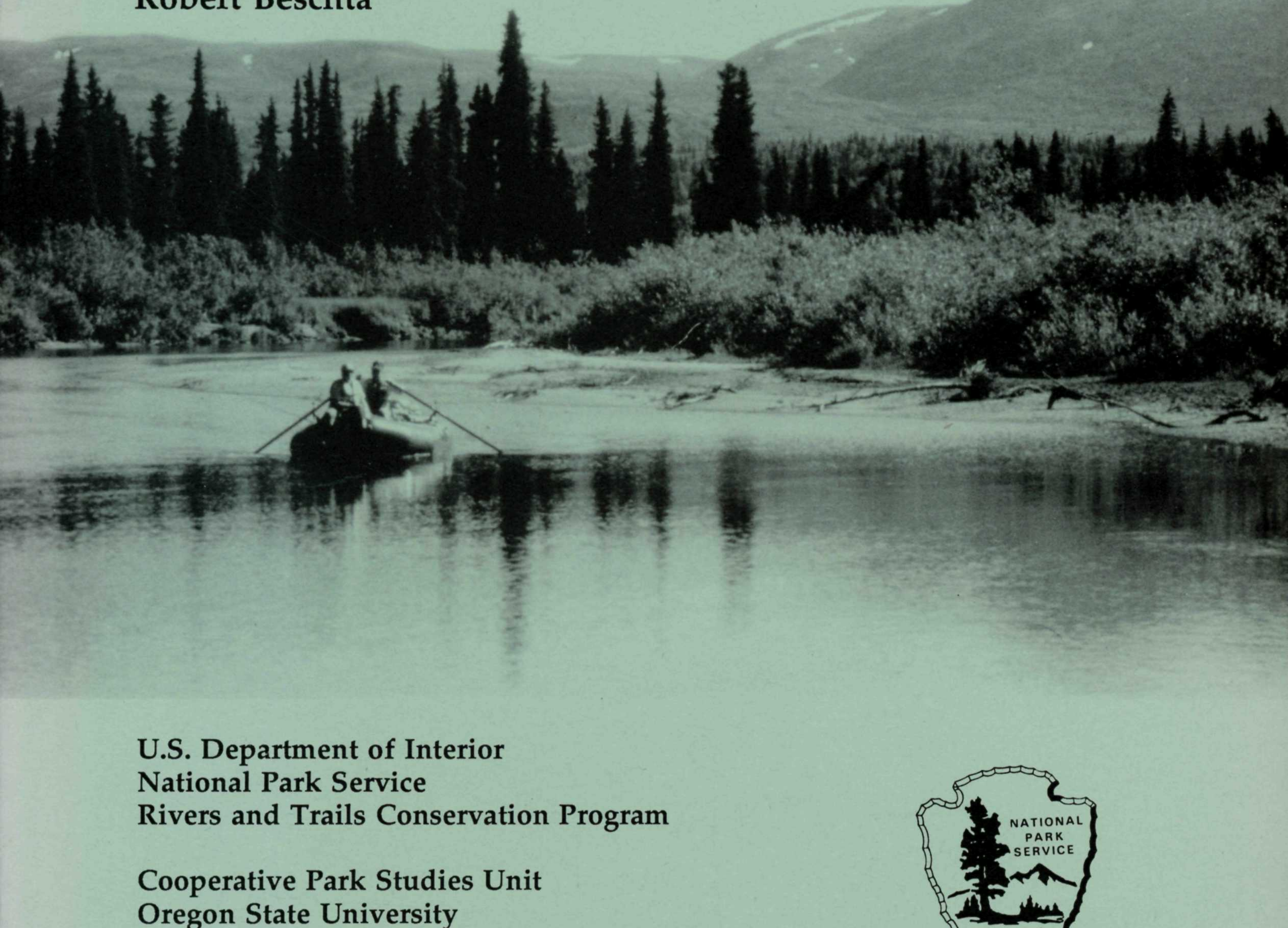

U.S. Department of Interior
National Park Service
Rivers and Trails Conservation Program

Cooperative Park Studies Unit
Oregon State University

National Park Service
Water Resources Division

1993

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January 1993

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This handbook was supported by

Rivers, Trails, and Conservation Program
National Park Service

in cooperation with

Cooperative Park Studies Unit, Pacific Northwest Region
College of Forestry, Oregon State University
(Cooperative Agreement No. CA-9000-8-006, Subagreement 24)

and

Water Resources Division
National Park Service

Additional copies of this publication may be obtained through the Alaska Region of the National Park Service, 2525 Gambell Street, Anchorage, Alaska 99503.

ABSTRACT

The quality of river recreation opportunities is dependent upon instream flows, but research exploring this relationship has been limited. Increasing concern over the impacts from out-of-stream water uses has led to interest in more rigorous efforts. The handbook provides a "road map" to the ideas and methods that are the basis of effective studies. The handbook presents a conceptual framework; a study process; approaches used to study the effect of flows on resource conditions; and approaches used to evaluate flows or conditions. Methods for evaluating flows is the central focus; advantages, disadvantages, and keys to the successful use of several methods are discussed. Several methods only provide preliminary assessments, while others such as survey-based methods or predictive modeling methods provide more comprehensive and defensible information. Examples of relationships between flow and important recreation attributes are also provided, including those for boatability, whitewater, rate of float travel, fishability, swimmability, and aesthetics. Other chapters discuss ways to explore trade-offs among the flow needs for different recreation opportunities and flow protection issues and strategies. Appendices contain example survey questions as well as a list of requirements for future studies.

Key words: recreation quality, instream flow, river management, water allocation, social science methods, experience definition.

PREFACE

Our job was supposed to be simple: Run the river, measure the flows, and estimate how much flow would be needed to maintain the river's recreation experiences. But which flows, and which experiences? We were four days into a seven day trip on Alaska's Gulkana River, and already we had encountered -- endured in some cases -- a full range of both.

Starting out in two overladen rafts and a snap-together vinyl canoe on a bright afternoon, we had learned it was possible to float down the narrow but relatively deep headwaters on a measured 26 cfs, while even three times that flow didn't allow us -- or the spawning king salmon -- passage through the riffles that appeared downstream as the channel widened. Making little progress pulling our rafts over the bars, we cheered the light rain that began to fall on our second day, a rain that turned into a full scale downpour by that afternoon. Unfortunately, the added flow did little to help our situation: the river had picked up gradient and now presented a boulder-choked channel. The river was running close to 300 cfs and had plenty of depth -- just enough to fill your hip waders -- but only the canoe was managing to find a clear route through. By the time we hit the upper river's only rapid, a short zig-zag gorge, the river was roaring but still couldn't provide a navigable run. We ended up lining the rapid.

"Boat dragging" on Alaska's Middle Fork of the Gulkana River at low flows.

The rain didn't stop that day, nor for two more, and the river reached its bankfull stage sometime after we had slogged through 35 miles of meandering flat water but before we got to the usually manageable Canyon Rapids, a quarter-mile Class III-IV run. We had almost been flooded out of one camp, and watched in dismay as cutbank after cutbank sloughed off into the river, turning the once clear green water into a muddy soup that killed the fabled salmon and grayling fishing -- at least for us. In the long run, of course, the erosion and the soon-to-come deposition were simply part of the dynamic system that nurtures good fish runs, not to mention creating expansive camping beaches for which the river is also known. But as we scouted the suddenly challenging whitewater of the Canyon, looking for a safe route around a huge hole at the end of the run -- and not even thinking about trying to measure the raging flows -- we began to fully understand the potential complexity of the instream flow issue.

Running the upper part of the Gulkana's Canyon Rapids at higher flows.

Conceptually simple, determining flow needs for recreation can often be practically challenging. The complexity begins with measuring flows, but extends very quickly to the relationship between different flows and the conditions that create a high quality trip. As an early study of its kind, we could have predicted the Gulkana would have much to teach us. But in the five years and dozen or so studies we have collectively worked on since, there is still much to learn.

In this handbook, we try to summarize some of the things we have discovered through our work. Not meant to be the final word on a field which is developing rapidly, our goal is to help establish a framework for bringing the field into maturity. Flows are a major ingredient in the river recreation recipe, but important as they are, it is surprising how little we know about them. In a world where no resource can be taken for granted, the recreation industry, planners, and the public are going to have to become much smarter about instream flows and the values that depend on them. There are many competing uses for the water in our rivers and policy makers are allocating and will continue to allocate water from them. Good allocation decisions --- decisions that include consideration of all the impacts --- will only be made with better information about those impacts. With this book, we hope to outline the steps toward providing that information for recreation.

We have many to thank for their help with this book. Institutional and research support for the handbook itself was provided by the College of Forestry at Oregon State University and the National Park Service's Rivers and Trails Conservation Program, while the studies upon which the book is based were also supported by the Bureau of Reclamation, the Bureau of Land Management, the National Park Service, the U.S Forest Service, the U.S Fish and Wildlife Service, the State of Alaska Department of Natural Resources, and the State of Alaska Department of Fish and Game. The handbook benefited from reviews of researchers, resource managers, and agency policy-makers, including Bern Collins, Thomas Brown, Bruce DiGennaro, Christopher Estes, Dan Haas, Tracy Miller, Jack Mosby, Dan Muller, Drew Parkin, Peter Skinner, Angie Tornes, and Owen Williams. Finally, numerous ideas in the handbook came from discussions with our colleagues on various instream flow studies. Co-researchers included Stan Carrick, Dave Ellerbroeck, Mary Lu Harle, Ron Huntsinger, Lon Kelly, Jon Kostoryhs, Larry McDonnell, Tony Martinez, Dennis Murphy, Don Prichard, Bunny Sterin, Jonathan Taylor, Steve Vandas, and Bruce Van Haveren.

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Chapter 1
INTRODUCTION

There are a number of important elements common to any quality river recreation trip. High on almost any list are scenery, a natural or natural-appearing environment, fish and wildlife. Depending on the river, the availability of good campsites, picnicking areas, or whitewater may also be important, as could the availability of solitude, quality fishing or hiking. In making such a list, a sufficient amount of water in the river -- the river's instream flow -- may not immediately come to mind. Too obvious perhaps, instream flows are critical to almost every other element on the list. Flows carve the scenery, nourish the environment and its fish and wildlife, create many of the best campsites, and generate the whitewater. Flows also dictate whether boaters can get up or down the river -- or how much fun they'll have trying to do so -- and whether people will want to swim or fish in it.

As important as instream flows may be for providing high quality recreation experiences, resource managers and researchers have spent relatively little energy studying them for that purpose. Faced with the loss of flows to out-of-stream uses such as hydropower and agriculture, the conservation community has long recognized a need to protect or maintain river flows. The bulk of this concern, however, has been focused on flows to keep the fish alive; and most instream flow research has been written by fish biologists. In recent years, people have begun to think more broadly. Flows have effects on any number of river values, recreational and otherwise, and policy makers are required to factor them into their water allocation decisions. The task at hand is to provide decision-makers with better information about flows and their effects on the full range of resource values.

The coming decade will bring increasing opportunities to maintain or obtain instream flows for recreation and other values. Both federal and state land managing agencies have shown heightened interest in using existing law and regulatory capability to secure instream water rights on designated rivers (Wild and Scenic rivers, State Scenic rivers, and so forth). At the Corps of Engineers and the Bureau of Reclamation, there has been a shift in policy focus from traditional flood control or irrigation to providing multiple benefits from water development projects, including downstream recreation needs. And at the Federal Energy Regulatory Commission (FERC), the agency responsible for reviewing more than 200 privately-operated hydroelectric projects under its re-licensing process, amendments to federal law have instructed regulators to give "equal consideration" to recreation and conservation by looking for ways to avoid, minimize, or mitigate adverse impacts.

To take advantage of these opportunities, recreation interests will need to develop better information about recreation flow needs, or the consequences of not meeting those needs. Increasing awareness of the full range of values that flows can provide has guaranteed that recreation values will be considered during water allocation negotiations. But this doesn't necessarily mean those values will be sustained. Out-of-stream water users know and can amply demonstrate what water they need. In order to successfully compete, instream water users must learn and show the same -- just as the fishery interests, to their credit, have been doing for the past couple of decades. Now is simply the time for recreation interests to develop similar knowledge and skills.

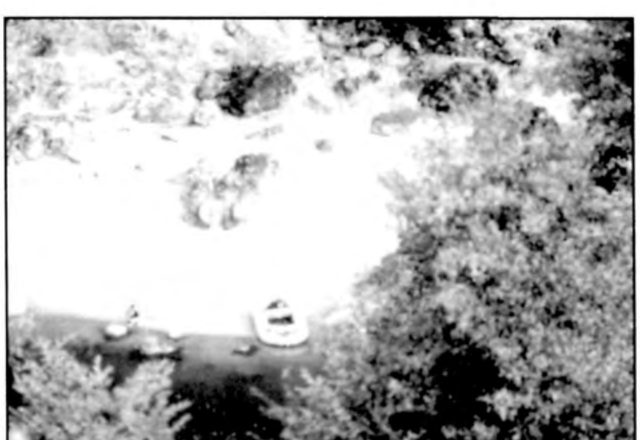

Figure 1. Flows play a critical role in creating and sustaining features of the river environment, including camping beaches on Oregon's Rogue River.

HANDBOOK GOALS

This handbook is designed to address the need for more systematic, rigorous, and defensible information about instream flow needs for recreation. Recognizing that such a document cannot provide all the knowledge and skills needed to develop and integrate information from fields as diverse as hydrology, geomorphology, planning, and social psychology, the handbook is not intended to be a comprehensive guide for conducting flow-recreation studies. Instead, the handbook is conceived as a "road map" to the ideas and methods that are the basis of effective studies. Following this analogy, the handbook is viewed as a compact tool for locating important ideas and suggesting how those ideas fit together in the research landscape, much in the way a road map can help a visitor identify important points of interest and suggest a route for exploring them.

The handbook's primary goal is to give researchers and the reviewers of research a common understanding of the issues involved in this kind of work. As opportunities to protect or maintain flows become apparent, interest groups, researchers, and resource managers will all need to participate in the development, execution, and review of flow-recreation studies. The more these groups can speak a common language, the better those studies will be.

Just as importantly, a common set of research principles can keep researchers from reinventing the wheel with each new study. Most studies to date have focused on a particular river and been based on the work of a very few people and ideas. At the first national workshops on the subject (in Corvallis, Oregon in 1990, and Williamsburg, Virginia in 1991), many participants were surprised about the number of other people doing similar work. By presenting ideas from a number of studies, this handbook can also help establish formal links and encourage dialogue among researchers working in different parts of the country. Such dialogue is a key ingredient for significant advances in the field.

A final hope for the handbook is to influence future studies so they become more compatible. Current studies, in addition to being conducted in a vacuum, also tend to focus on single segments of rivers and finite sets of recreation activities. As a result, the flow needs for one river often cannot be compared with those from another. There is nothing inherently wrong with this approach, which is designed to address specific resource management needs. However, if data from enough rivers can be collected in a similar way, it may be possible to establish a link between flow needs for specific types of recreation and easily-measured hydrologic characteristics of rivers. Fishery biologists have managed to do this for a variety of aquatic species, and the resultant models have proved useful. A long-term goal of recreation research is to develop parallel models. Conducting studies and presenting data in similar ways, as suggested in this handbook, is a necessary first step in meeting this goal.

Figure 2. Swimming in California's Clavey River. Instream flows affect the quality of a variety of recreation opportunities, including boating, fishing, hiking, and swimming.

HANDBOOK AUDIENCE

The handbook is intended for a lay audience interested in the technical aspects of streamflow effects on recreation. Although conducting studies requires specialized technical skills and carefully developed research methods, the principles involved are comprehensible to non-specialists. With the handbook's help, earnest readers should be able to understand the logic of these studies and become critical consumers of them.

The handbook is also intended for researchers and decision-makers. Researchers sometimes complain that their work is not used as often or as well as it should be, while managers sometimes complain that researchers produce information less understandable or usable than it could be. In this handbook we try to address both complaints. On one hand, we have tried to avoid the "black box" syndrome whereby incomprehensibly complex models provide the only answers to important questions. Decision-makers, often lacking statistical sophistication, are rarely willing to invest in such approaches; if they are going to defend a decision, they must be able to grasp the basis of it. On the other hand, we have also tried to avoid oversimplifying complex relationships just because the simple is easier to understand. A flow need represented by a single number is easier to talk about than a range of needs represented by a curve. Nonetheless, as we will argue throughout, it is both more realistic and theoretically appropriate to talk about the incremental impacts associated with a full range of flows.

The field is still young and methods are being developed and tested. The results are not all in. However, policy makers are asking questions and researchers are being told to find the answers. Through the development of the ideas in this book, we hope to provide a structure in which the questions are better framed, the answers are better understood, and the policy decisions are more informed.

HANDBOOK ORGANIZATION

The handbook begins with a discussion of basic principles and the presentation of a conceptual framework for doing flow-recreation studies. It then outlines a process for conducting any kind of instream flow research, whether for recreation or other resource outputs, essentially developing a checklist of issues that quality studies should address.

The book then expands on the central issue in the process as it applies to recreation: developing relationships between flows and various recreation "outputs," or recreation opportunities. Depending upon the river and its values, there are a variety of different methods or approaches that could be used. The handbook first explores methods for developing relationships between flows and resource conditions, then looks at methods for evaluating those flows or conditions. Following this, a chapter presents a series of typical flow-output relationships as examples of the information studies will be producing. These examples also allow further discussion of appropriate methods in varying situations.

The final chapters of the handbook explore various ways of integrating information about different flow needs to develop flow recommendations and the common flow protection strategies that can be used to implement those recommendations. The heart of the link between science and decision-making, these discussions focus on ways to develop realistic and understandable alternatives from which informed decision-making or negotiations can proceed.

Throughout the handbook, information is presented in both the main text and a series of "sidebars" and appendices. Sidebar topics include discussions of standard hydrology methods, normative theory, survey research, and applying fishery methods to recreation, while the appendices include examples of survey questions, a list of study requirements, and a glossary of terms. The handbook also includes a list of references at the end of each chapter for readers interested in greater detail about particular subjects.

References and Suggestions for Further Reading

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Notes:

Chapter 2
A CONCEPTUAL FRAMEWORK

Assessing instream flows for any resource (including recreation) requires a conceptual understanding of how different flows or flow regimes affect various, and potentially competing, river resources. This chapter presents such a conceptual framework (see Figure 3) and explains its main elements: **flow, resource conditions, resource outputs,** and **trade-offs and flow negotiation.** In subsequent chapters, these elements and the relationships between them are explored in greater detail as they relate to recreation.

FLOW

Flow is the variable driving the system in any instream flow study. The amount and timing of flows (which define the hydrology of the system) are the first variables which need to be understood. The simplest case is a natural flow regime on a river with no human intervention ("unregulated systems"). In systems with human interventions such as dams, withdrawals, or diversions ("regulated systems"), complexity is added with various operational variables. In both cases, instream flow studies start by describing the range of water regimes and operational variables that produce water in the stream. These factors are represented by the faucet in Figure 3, recognizing that the faucet is controlled by some combination of natural and human factors.

RESOURCE CONDITIONS

At the most fundamental level, flow has a major impact on resource conditions. The conditions responding directly to flows are river hydraulics: water depth, velocity, width, wetted perimeter, and turbulence. "Indirect" responses also occur becuase of the interactions between flows and sedimet process and riparian vegetation. Indirect impacts include changes in channel features such as sinuosity, sediment movement, channel movement, gravel bars, and beaches. Indirect impacts also include changes in characteristics of riparian vegetation such as the type, amount, and location of plants, as well as the physical and chemical make-up the river, its water quality.

Hydraulics, channel morphology, and riparian vegetation respond to changes in flow, forming a dynamic interactive system that defines biological and recreation habitats. For example, when rivers flood, they become erosive and carry considerable amounts of sediment. During these periods, bars are formed and meanders adjust and migrate. Floodplain vegetation may cause sediment to settle out, creating rich riparian soils. Many of these flood-dependent processes in turn create habitat and transport seed for early successional-stage vegetation. The resulting channel form may provide water to later-stage vegetation such as large cottonwood trees.

Because recreation opportunities often depend upon the **character** of the river and associated floodplain, it is important to consider how stream flows affect river hydraulics, channels, and riparian zones. Conversely, when identifying optimum stream flows for activities such as rafting or canoeing, it is also important to consider the effects those flows might have on resource conditions. Understanding the relationship between flow regimes and resource conditions is the subject of Chapter 4, Exploring the Effects of Flow on Resource Conditions.

RESOURCE OUTPUTS

The unique array of resource conditions associated with a given river provide different instream resource outputs. These include fish habitat, wildlife habitat, and various types of recreation opportunities. Within each category, there may be several alternatives. For example, different flow regimes may produce habitat for different types of fish or wildlife, or different types of recreation. These are the "products" to be evaluated in an instream flow study, analogous to "goods and services" produced in an industrial setting.

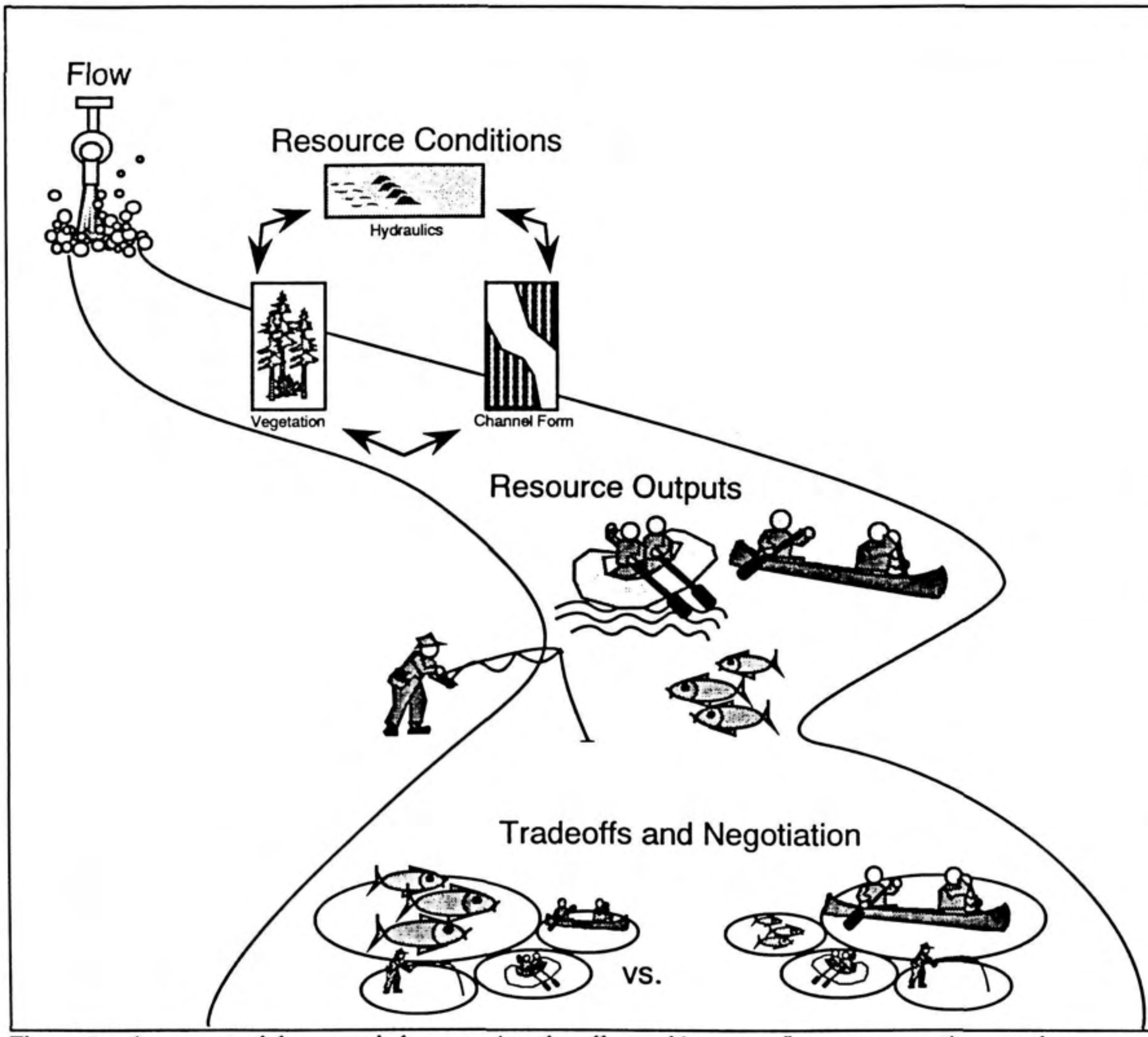

Figure 3. A conceptual framework for assessing the effects of instream flows on recreation or other resource outputs.

Interestingly, this model could also be adapted to explore how different flows produce different out-of-stream resource outputs such as power-generation capacity, or irrigation capacity. In this case, however, "resource conditions" would refer to characteristics of the out-of-stream water use. Specifying recreation outputs and a discussion of the methods available to evaluate alternative outputs at different flow levels is the subject of Chapter 5, Evaluating Conditions or Flows. Chapter 6, Examples of Flow - Attribute Relationships, presents further information on the flow- output link.

TRADE-OFFS AND FLOW NEGOTIATION

At this stage, it becomes apparent that different flow regimes can produce many different combinations of resource outputs. Deciding on a specific flow regime means moving from the technical arena (where scientists and resource specialists determine how flows affect resource conditions and outputs) to the political arena (where decision-makers, resource managers, and interest groups evaluate and negotiate the desirability of different combinations of outputs). This process involves assessing trade-offs between scenarios. One scenario may offer an ideal power-generating regime, but less than ideal fish habitat or whitewater boating. Another scenario may offer the highest quality whitewater, but less ideal power generation and a shorter season for non-whitewater boating.

The initial array of scenarios may seem so numerous to be overwhelming, but negotiation and decision-making face a number of constraints. These may include physical constraints such as the amount of water available or the operational limits of a dam (assuming the river is regulated), legal or administrative constraints such a legislative or agency mandates, and political constraints such as long-established positions that are unlikely to change. These realities of the "flow negotiation environment" may quickly narrow the field to a more manageable set of alternative scenarios.

It is then necessary to determine the relative merits of different scenarios, a process which involves valuation, optimization, and a final management decision. Technical information will need to be integrated with social value judgments. For example, is it better to provide minimal boating conditions for extended periods of time, or optimum conditions for shorter times? Should riparian conditions or fish habitat be altered to accommodate flood control or power generation? Should family boating opportunities be provided at the expense of whitewater boating? In all cases, instream flow studies that permit the evaluation of alternative flow scenarios representing realistic combinations of resource outputs are more useful than studies that use some "formula" to develop a single flow regime. Chapter 7, Trade-offs and Flow Scenarios, further explores the central issues of this integration process.

References and Suggestions for Further Reading:

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Chapter 3
DESIGNING AN INSTREAM FLOW STUDY

Instream flow for recreation is an applied science issue. While many researchers and consultants work from a well-developed theoretical perspective, almost all flow-recreation work is applied research supported by resource managers facing a flow allocation opportunity or threat. Accordingly, that work should be designed to fit into existing decision-making processes. This chapter presents a step-by-step process designed to integrate the conceptual ideas of the previous chapter with the realities of resource planning.

Adapted from an approach developed by BLM researchers (Jackson et al., 1989) and similar to other processes developed by fisheries researchers (Estes and Orsborn, 1988), this process is best viewed as a general outline for studies rather than a fixed set of steps. Like any process, adaptations may be necessary to fit resource, political, or administrative realities, and some studies may only need to address a few steps because a larger planning or negotiation process will be addressing the remainder. In any case, the process serves as a checklist of ideas that researchers should consider, as well as a structure for organizing those ideas. Readers should note that most of the steps in the process are described in their entirety, although others are more briefly discussed because subsequent sections will expand upon them. When that is the case, it is noted.

Step 1:
DEFINE THE STUDY PURPOSE AND OBJECTIVES

This step simply emphasizes the need for clarity in conducting and presenting research. Completing this step includes:

- ❑ Defining the study area, and the limits of generalizing findings beyond the study area. A simple map (a schematic is often sufficient) of the study area should be considered a requisite element in any report.

- ❑ Defining the type of recreation the study will address. Will the study document only boating flow needs, or will it explore flow needs for streamside hiking, birdwatching, sightseeing, or other recreation activities closely tied to the river? Will it examine only the needs of current recreation opportunities, or will it look at potential opportunities as well? Flow needs are specific to a recreation opportunity; those under examination should be explicitly listed at the outset.

- ❑ Defining the end-point of the study. Some flow studies will stop with the discovery of flow needs for specific recreation opportunities, while others will attempt to

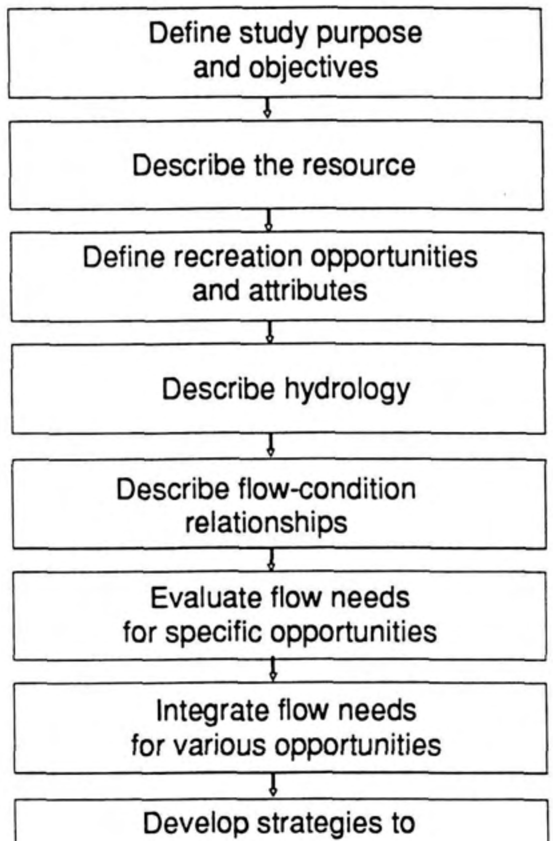

Figure 4. A process for conducting studies of instream flow for recreation.

integrate flow needs for other opportunities, other instream uses, or other out-of-stream uses. A high quality study should specify its ambitions from the beginning, and if they are limited, describe how they will be inserted into the larger process. Information about flows and recreation can easily be lost if it is not designed to fit into the negotiation or planning process. For example, studies on regulated rivers may focus on changes in dam operation guidelines (using an existing water budget more judiciously) or changes in water allocation (increasing the water budget), while studies on unregulated rivers focus on documenting flow needs before out-of-stream users have made their requests (reserving water prior to the existence of a water budget). Discussing a study's end-point forces the researcher to examine and address management's perspective, and can vastly improve the study's usefulness.

Step 2: DESCRIBE THE RESOURCE

High quality research depends on a broad base of knowledge about a resource, and studies should demonstrate this knowledge through resource summaries. This step simply emphasizes the need to put the resource and the recreation flow need issue in a larger context. The depth of this analysis, of course, depends on the scope of the study and the existence of other documents with this information, but a brief summary seems useful in almost any case. A high quality summary generally includes information about the following:

- ❑ The physical resource, including the region's climate, geology, terrain, vegetation, and cultural resources. This should include a brief discussion of the type of river and the regional context.

- ❑ Fish and wildlife resources, particularly those for which instream flows are often critical (threatened and endangered species, sport fish species, etc.).

- ❑ Recreation activities and use, as well as visitor facilities (including access points, campgrounds, parking areas, nearby commercial facilities such as stores, lodges, etc.).

- ❑ The significance of the river's recreational resources in the region, as well as potential substitutes.

- ❑ Governmental history and agency responsibilities. This should briefly identify agency mandates, legislative or agency designations, planning documents, or informal management policies for the river that delineate the decision-making environment into which the study will be placed.

- ❑ Land use and land ownership. Summary tables are often sufficient for land ownership. Summary descriptions are more important for development issues, particularly those which might require out-of-stream water uses.

- ❑ Formal and informal groups that have an interest in the resource or flow issues.

Step 3: DEFINE RECREATION OPPORTUNITIES AND ATTRIBUTES

Defining the recreation opportunities for which the study will determine flow needs is a critical evaluative step. While recreation opportunities should have been broadly identified in the study objectives, this step discusses them in much greater detail. This is where a specific kind of recreation opportunity its important characteristics are identified.

The hard part of this step is being specific; most plans and studies are not. In many cases, similar recreation activities are grouped together (sailing and boating, rafting and canoeing, fly-fishing and bait fishing, etc.) even though there are often important flow need differences between them. In fact, even people engaging in the same activity may have different flow needs, depending upon the type of experience they desire. Compared to an advanced canoer, for example, a novice paddler may have very different ideas about flows needed for a challenging run through a rapid. If research is to examine these differences, it will have to begin with far more information about recreation experiences than the activity alone.

One useful way to define recreation experiences in more specific terms is to discuss them in light of "recreation attributes." A recreation opportunity is not some abstract concept, but a collection of measurable conditions that can be evaluated relative to various standards. A high quality experience is a trip where certain desirable conditions exist; a low quality trip is one where those conditions are lacking.

Table 1 provides a list of experiences we have examined in various studies of rivers in Alaska and Colorado. The list helps suggest the level of specificity needed in this step. Note the specific descriptions used to name different experiences; the type of activity is simply the starting point. For each experience, a list of attributes should also be developed to expand upon the descriptive name. Table 2 contains a list of flow-related recreation attributes (a sub-set of all attributes) from those same studies. Not intended as an exhaustive list, these examples are provided to suggest the range of possibilities. Once again, the level of specificity is critical. Ultimately, a researcher will be examining and evaluating flow needs for each of these attributes.

Developing recreation attributes can be a difficult task. Although most researchers and managers have little trouble making an initial list for a given type of recreation, some form of public input will ultimately be needed for verification. Users are experts about their trips and the things that make or break them, and research has shown that professionals do not always know which conditions users prefer. There are a variety of methods that may be used to better understand users' trips and the conditions that determine their quality. A discussion of those techniques is presented in Chapter 5, Evaluating Flows or Conditions.

Table 1. Some examples of recreation experiences used in flow-recreation studies. There may be more than one experience for a given activity or river segment and the flow needs for different experiences may be different.

River	Examples of "Experiences"
Little Susitna River, Alaska	Extremely challenging whitewater kayaking (Class V-VI) Challenging whitewater kayaking (Class III-IV) Jetboating / inboard powerboating Powerboating (smaller engines) Driftboat fishing Bank fishing Hiking along upper river
Lake Creek, Alaska	Whitewater rafting/kayaking Wilderness floating Drift fishing on lower river
Dolores River, Colorado	Challenging whitewater rafting/kayaking "Scenic" rafting/kayaking Technical whitewater canoeing "Scenic" canoeing "Canoe-hiking"

Table 2. Some examples of flow-related "trip attributes" used to define various recreation experiences. Developing a specific list of trip attributes is a critical step in the process because attributes define the conditions for which flows are needed.

Category	Examples of Attributes	Category	Examples of Attributes
Boatability	No major portages Few hits in boulder gardens Clear channel through riffles No engine damage due to groundings	Camping	Scenic views of river Open and flat areas for tents Access (eddies for take-outs) Sandy beaches Lack of insects
Whitewater	Major rapids are Class III/IV Long reaches of Class II rock-dodging Large standing waves at constriction rapids Keeper holes at two major rapids	Fishing	Open bars for casting Clear water (low turbidity) Wadable depths & velocities Good fishing water (holes or riffles -- depends upon the species, type of lure, etc.) Variety/abundance of fish
Rate of Boat Travel	Trips require less than 2 days given 4-6 hours/day on river	Scenery/ General River Aesthetics	Open views Active geological processes Few traces of human use Variety of wildlife Sound/smell of river Power of waterfalls/rapids Water clarity
Hiking	Access to side canyons Open point bars for hiking and views		

Step 4: DESCRIBE HYDROLOGY

Hydrology is the quantity and timing of water availability in a river system. Quantifying a river's annual hydrologic regime is an essential element in defining the range of flow management options -- in the conceptual model, it is the "faucet" from which all other elements in the framework originate. Information about current or potential flow regimes is the starting point for an instream flow analysis.

In describing hydrology, researchers need to consider not only the river's natural hydrology (how much water naturally flows in a river through a period of time), but also the ways in which that hydrology may be altered by dams, diversions, or withdrawals. On highly regulated streams, hydrologic regimes may be permanently affected by these structures, imposing severe constraints (or opportunities) on flow management options.

There are a variety of techniques for exploring the hydrology of a river, many of which are discussed in greater detail in Chapter 4, Exploring the Effects of Flow on Resource Conditions. In almost any study, however, researchers will need to demonstrate a basic understanding of the river's hydrologic regime through a brief summary. Information generally included in this summary (which should be a **summary**, not an infinite appendix) includes:

- ❑ Representative hydrographs, showing how average flows change over the course of a year (or the season of interest).
- ❑ Low-flow and high-flow analyses that show when and how often low or high flows (including peak flows) are likely to occur.
- ❑ Pre- and post-project flow regimes when the

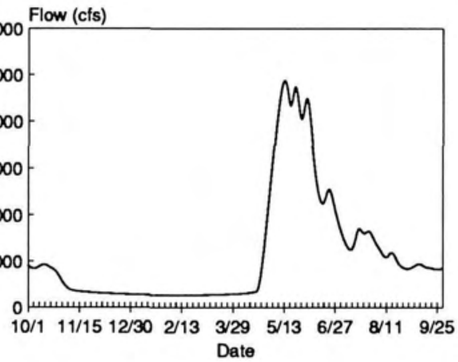

Figure 5. Annual hydrograph (mean daily flows) for Alaska's Gulkana River. Hydrographs provide key information for instream flow studies.

river system in question is regulated, as well as a discussion of the changes from natural flow resulting from any water development projects. This includes a discussion of operational constraints for any projects.

Step 5: DESCRIBE FLOW-CONDITION RELATIONSHIPS

This step establishes the link between various flow levels (the hydrology of the river) and the conditions that create recreation opportunities. However, this is the descriptive side of the equation: the information generated here should ideally show how conditions change with different flows or flow regimes, not evaluate those different conditions.

In many studies, particularly those focusing on long-term or indirect effects of flow on channel features or vegetation, this step is at the center of the effort. In these cases, examining the flow-condition link is a prerequisite for evaluating those specific conditions. In other cases this step may be partly bypassed because the flows themselves can be evaluated. For example, it is often possible to have boaters directly evaluate flows for certain recreation attributes such as boatability or whitewater without bothering to learn the details of how different flows affect specific whitewater or boatability conditions (e.g., water depth or velocity). The more researchers know about the flow-condition link, the better they can understand any subsequent evaluations, and the more likely that "generalized" methods can be developed. Almost any study should provide at least a qualitative analysis of that relationship.

Output from this step comes in one of two forms, depending upon the type of conditions under examination. For conditions directly affected by flows, information should show how conditions will change through a range of flows (incremental relationships). One basic example of this relationship might show how depths in riffles change through a range of flows. A more complex example of a flow-condition relationship is given in Figure 6, showing how increases in flow decrease the number of times rafts run aground in shallow areas. In this case, the condition of interest (number of "hits") depends on more basic conditions affected by flow (depth and perhaps velocity), but it still refers to a non-evaluative and measurable variable. Similar curves could be developed for floaters' rate of travel, size and frequency of rapids, availability of gravel bars for fishing or camping, or other attributes of a trip.

For conditions that are more indirectly affected by flows, incremental relationships may be more difficult to develop. In these cases, changes are typically longer term and/or subtle and researchers must often take a step back to gain perspective. In most cases, the goal is to link different flow regimes with the trends in various conditions. A common example of this type of analysis would be a relationship between average peak flows and the creation or maintenance of channel features such as beaches, sloughs, or riffles.

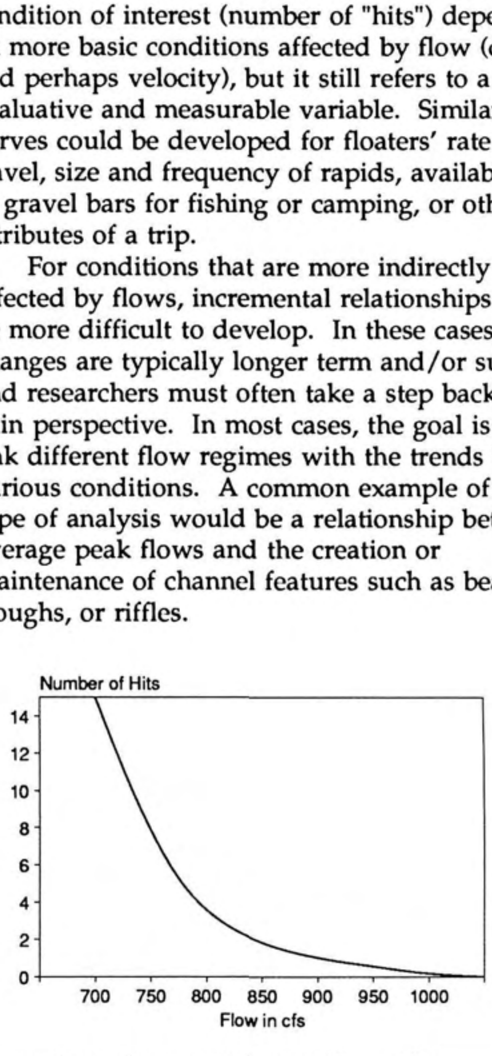

Figure 6. An incremental curve shows the relationship between flows and a measurable resource condition (in this case, the number of hits reported by rafters). Data come from Colorado's Dolores River.

There are a variety of methods for examining flow-condition relationships, each having advantages or disadvantages that depend upon the circumstances of the river and the opportunities or attributes in question. The next chapter in the handbook, Exploring the Effects of Flow on Resource Conditions, provides more information on these methods and how they can be used to develop flow-condition relationships.

Step 6: EVALUATE FLOW NEEDS FOR SPECIFIC OPPORTUNITIES

This step develops the evaluative side of the equation, providing information about the best or preferred conditions or flows. The idea here is to identify the conditions and flows (or flow regimes) that are best for each particular recreation opportunity.

There may be two or three parts to this step, depending upon whether the evaluation begins with flows or conditions. If the study begins with conditions, those will need to be evaluated first. After this, the preferred flows (those that create preferred conditions or those directly evaluated as preferred flows) can be identified for important attributes of the opportunity, which may involve one or a combination of conditions. Finally, the range of preferred flows for various attributes must be integrated into an overall flow evaluation for a specific opportunity.

As an example, think about an effort to evaluate flows and conditions for a bank fishing opportunity. It might begin with specific evaluations of flow-dependent conditions such as wadeability, turbidity, and water temperatures at different flows. Researchers would document the combinations of depth and velocity best for wading (and thus determine which range of flows provide preferred combinations), as well as determine the flows that provide preferable turbidity or temperature levels for catching fish.

But this information alone is not sufficient. Assume, for example, that after making these initial evaluations, researchers discovered that on this river lower flows provide better wading and clearer water, but they also mean higher temperatures, less active fish, and thus lower fishing success. In contrast, higher flows and corresponding lower temperatures bring better fishing success, but increased turbidity at very high flows eventually lowers that success, and the higher flows are increasingly unwadable as well. Taken singly, the preferred flow for each condition may be very high or very low; taken together, some medium range of flows appears to provide the best overall evaluation. Only when evaluations for all the important conditions are integrated can an overall flow preference be identified. In most cases no single flow or narrow range of flows will provide optimum conditions for every attribute of a recreational opportunity. In order to fully evaluate a range of flows, it is thus necessary to examine flow needs through some sort of optimizing filter.

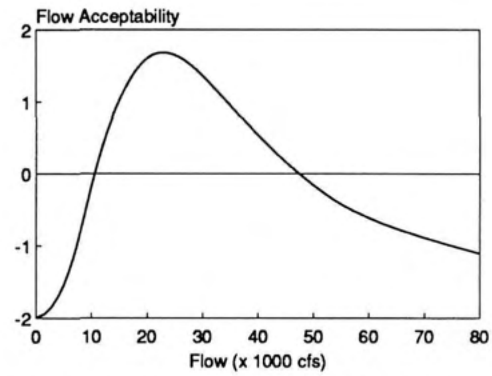

Figure 7. Example of an overall flow preference curve for whitewater boating in the Grand Canyon. The curve is based on evaluations by commercial guides and private trip leaders.

The output from this step again depends on whether effects are direct or indirect. For direct effects, the ultimate goal is an incremental curve that shows how recreation quality changes through a range of flows. An example of such a curve, which is also known as an overall flow preference curve, is given in Figure 7. Readers should note that this curveonly shows the "best" flows for whitewater boating in Grand Canyon and does not provide any information about best flows for maintain the Canyon's fishery or its beaches.

For indirect effects, information is generally organized in more descriptive terms. The goal in these cases is to evaluate alternative flow regimes (or critical elements of those flow regimes) rather than a simple range of flows.

There are a variety of methods involved in executing this step, and subsequent chapters explore those methods in greater detail. Chapters 4 and 5 discuss the range of methods being used in flow studies, many of which offer techniques for evaluating conditions or flows. Sections of Chapter 7, on developing flow need recommendations, also address the integration tasks inherent in this step.

Step 7: INTEGRATE FLOW NEEDS FOR VARIOUS OPPORTUNITIES

At this point in the process, flow needs for individual opportunities or resource qualities have been clearly defined. The next step is to integrate those needs with each other. This is another evaluative step which may require balancing different and often competing flow needs for various opportunities. For example, one flow regime may provide excellent trout fishing and scenic boating, but would fail to provide a high quality whitewater opportunity. The goal here is to develop a flow regime (or range of alternative flow regimes) that considers the trade-offs of providing different opportunities.

The best integrations will provide for many opportunities, but in some cases the "elegant solution" may be more difficult to find. On a regulated river, the goal is to find a balance among opportunities in light of the river's traditional uses, policy mandates, and potential to provide the highest value opportunities or resource outputs. On an unregulated river, the goal is to protect existing high value opportunities or resource outputs. In either case, decisions may come down to interest group politics and the vagaries of resource planning. However, a good study will help improve that planning process by providing a structure to focus discussion and debate. In this step, you build that structure through an explicit discussion of trade-offs and flow regime alternatives.

Chapter 7 of the handbook explores some of the techniques that can be used to complete this step, including a discussion on the development of "flow scenarios" or flow regime alternatives. That chapter also discusses integrating flow needs for various recreation opportunities with the flow needs for other resource outputs such as fish or wildlife habitat, hydropower generation, or withdrawals for industrial activities, municipal water supply, or agriculture.

Step 8: DEVELOP STRATEGIES TO PROTECT/OBTAIN FLOWS

The final step in the process is to develop a strategy to obtain or protect instream flows. This step requires evaluating and blending legal, administrative, and technical alternatives to maintain or enhance flow-dependent values. The strategy needs to be realistic, administratively efficient, and as flexible as possible in recognizing the many overlapping and competing interests for instream flows. It is out of the scope of this document to discuss the full range of legal options for protecting or obtaining instream flows. In general, the primary focus will be on establishing an instream flow water right under applicable state law. However, alternative water rights strategies should be evaluated, including the reserved rights doctrine and opportunities for acquiring or transferring existing rights.

The keys to protecting a water right are specifying an amount that protects resource values, quantifying the right so that it can be realistically measured and protected, establishing a meaningful priority date in relation to competing water uses, and developing an effective administration strategy.

An instream flow assessment might consider other (nonlegal) administrative and technical options to support the purposes of an instream flow water right. For example, water control structures and watershed management techniques may be used to regulate runoff and streamflow to meet instream objectives. Rights-of-way permitting and land purchase and exchange may also be used to curtail consumptive uses of water that conflict with instream flow objectives. Land management, such as proper floodplain development, control of access, or management of riparian vegetation, may enhance values or processes for which instream flows are required. Finally, agreements or binding contracts between instream water interests and major water users or reservoir operators may be used to manage instream flows.

Chapters 7 and 8 on Trade-offs and Flow Protection Strategies presents a brief summary of the ways instream flow research can be integrated into flow negotiation processes.

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Notes:

Chapter 4
EXPLORING THE EFFECTS OF FLOW ON RESOURCE CONDITIONS

Instream flow decisions are decisions affecting stream hydrology. However, a meaningful instream flow analysis also requires an understanding of the relationship between a river's flow regime and associated hydraulic, geomorphic, and riparian vegetation conditions.

Often passed by because of their complexity, these relationships can be critical for exposing significant impacts to a river's biotic or recreational resources. Rivers are dynamic over both the short and long term; ignoring the latter can put valuable resources at risk. In order to understand and characterize the interplay between flow and various resource conditions, researchers need information about the following areas, each of which are discussed in subsequent sections of this chapter.

- Quantification of the river's **hydrology** (the amount and timing of flows).
- Quantification of the river's **hydraulic geometry** (how flows affect associated hydraulic variables such as depth, width, velocity, and wetted perimeter).
- Description of the river's **landscape position and river type** using a geomorphically-based river classification system.
- Integration of hydraulic geometry and related **geomorphic processes** or conditions, especially those affecting the responses of channel and depositional areas such as beaches, bars and floodplains to changes in hydrology.
- Assessment of how flow regimes influence the character and type of **riparian vegetation.**

The reader should keep in mind that these are complex technical subjects which are only treated briefly here. For a more complete discussion, see standard hydrology texts such as Water in Environmental Planning (Dunne and Leopold, 1978), The Fluvial System (Schumm, 1977), or the U.S. Geological Survey guidelines on hydrology field techniques (see references at end of chapter).

HYDROLOGY

Hydrology refers to the amount of water in a river and the timing of flows (e.g., daily, monthly, or annually). Some of the most useful hydrologic descriptors for framing an instream flow quantification are mean monthly flows through they year and median daily flows for each month. Mean monthly flow indexes the amount of water available for instream allocation each month (Figure 8) and in the typical form shows how these are distributed throughout the year. Historical monthly maximums and minimums can also be useful for indexing the range of variability. In contrast, median daily flows provide more detail about changes through a given month. This situation is especially important in arid and semi-arid stream systems, where infrequent high discharges can greatly skew

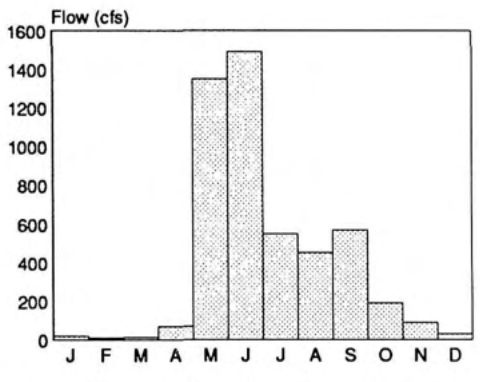

Figure 8. Mean monthly flows provide an overview of the water likely to be in a river over the course of a year. (Data come from Birch Creek, Alaska).

the distribution of daily flows in any given month, thus providing less useful mean monthly measures.

Both mean monthly and median daily flows can be readily determined from stream gage data (typically compiled by USGS). When stream gage records are unavailable for the river in question, analytical methods can often be employed to construct the needed flow statistics using gage data from similar streams in the region. On highly regulated river systems such as the Colorado or Columbia, hydrologic models have been developed to determine long-term records under various dam operating rules.

Several other hydrologic variables are also useful for describing a river's annual flow regime. A flood frequency analysis describes flood size in relation to its probable frequency of occurrence (Figure 9). This information is often of particular importance in evaluating fluvial and riparian processes which generally depend on high flow events. In similar fashion, low-flow frequency analyses quantify the lowest flows likely to occur over periods of days or months (Figure 10), helping identify periods of critical water shortage.

While analysis of annual hydrologic regime is necessary for an instream flow assessment, in many cases it is not sufficient. It is often important to know stream discharge or flow at a specific site on the river during field work. If a river is gaged, the flow records will be available for a particular gaging station. If such a station is located up- or down-river from the reach of interest, however, extrapolation of flows may be required. In the case of an ungaged river, field measurements of stream discharge using standard techniques may also be necessary (see the sidebar on page 19).

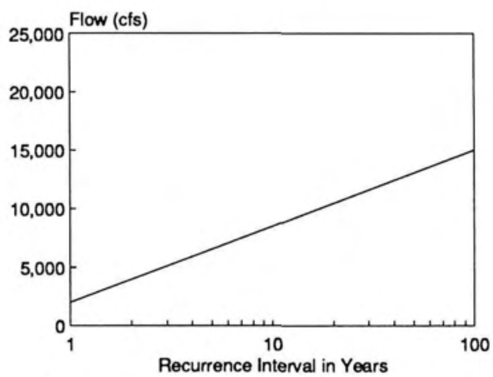

Figure 9. A peak flow analysis (also known as a flood frequency analysis) shows how often floods of a certain size are likely to occur. Data come from the Dolores River prior to construction of McPhee Dam.

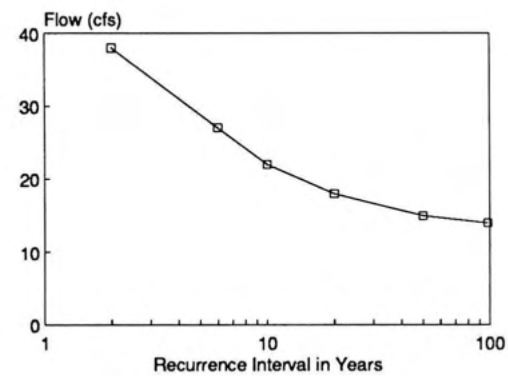

Figure 10. A low flow analysis shows how often low flows are likely to occur. Data come from the Dolores River prior to the construction of McPhee Dam.

Measuring Streamflow in the Field

Stream discharge (Q) is defined as the volume of water that flows past a given channel location per unit time (e.g., cubic feet per second, or cfs). It is calculated as the product of the cross-sectional area of the wetted channel times the average water velocity.

Because local stream velocities vary greatly with depth and distance from the river edge, discharge measurements in the field are based on dividing a river cross section into numerous subsections. For each subsection, a cross-sectional area is calculated from width and depth measurements and the velocity is measured for each subsection using a current meter (Figure 11). The calculated discharge for each subsection (i.e., subsection cross-sectional area times the average velocity of the subsection) is then summed to obtain the total stream discharge or flow.

If individual flows are measured for several river stages, it may be possible to construct a flow "rating curve." A rating curve is a graphical plot of river stage (i.e., vertical water level) vs. flow (Figure 12). Once a rating curve is established, it is possible to estimate flow from a measure of river stage, such as marks on a bridge pier.

Flow measurements in cfs give the appearance of great accuracy and are sometimes reported to one or two decimal places. However, as the above procedures should make clear, several aspects of flow measurement introduce error into the calculation. People who have a great deal of experience measuring flows in the field are always careful to qualify the accuracy of their measurements. Those of us who rely on their measurements should respect this caution. As a rule of thumb, any given flow measurement, even if calculated via sound methods, is only an estimate of the actual flow and may easily be off by five to ten percent. This notion is particularly useful to remember at the negotiating table when competing water users are arguing over a small difference in flows.

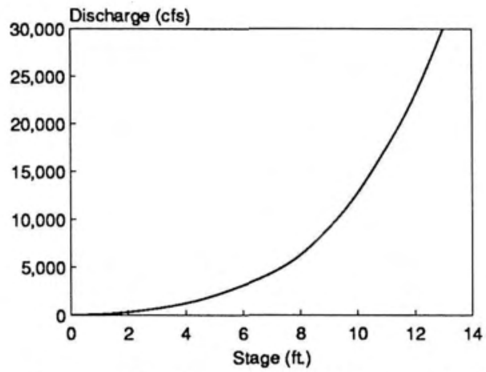

Figure 12. Example of a rating curve from the San Pedro River, Arizona. The table allows researchers to use stage information (vertical height of water) to determine flow at a transect site.

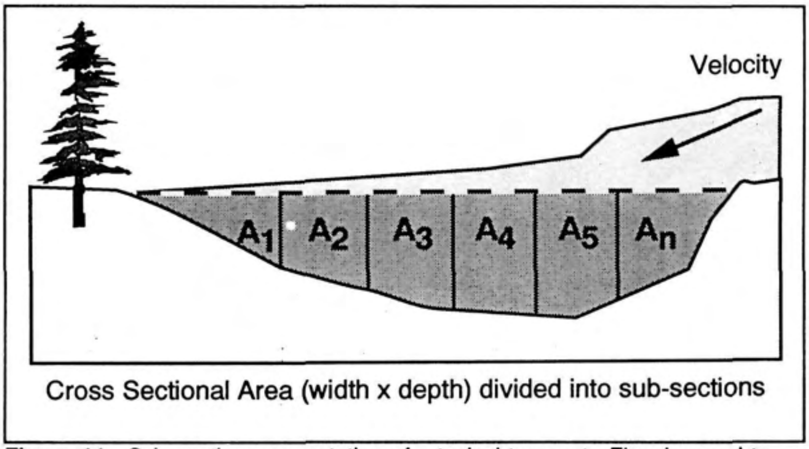

Figure 11. Schematic representation of a typical transect. Flow is equal to the product of velocity times the cross sectional area. In the field, measurements are made for each subsections and then summed.

HYDRAULIC GEOMETRY

Understanding the effects of flow in a river requires information about the river's hydraulic geometry. **Hydrology** describes how much water is available and its discharge over a period of time. **Hydraulics**, in contrast, characterize the important components of flowing water: depth, velocity, size of waves, the proportion of a stream channel and floodplain that is inundated, the quantity of sediment a particular flow is capable of transporting, etc. Hydraulics are obviously critical when looking at the direct effects of flow, but they play an important role in exploring indirect effects as well.

When specific hydraulic variables are expressed as a function of flow, "hydraulic geometry" relationships can be developed. As in the example given in the sidebar on page 21, these relationships can help researchers decide which flows will provide adequate boating depths or which will inundate camping beaches. Hydraulic geometry calculations are also the starting point for exploring potential changes in geomorphology or riparian vegetation. For example, researchers exploring how different flows affect the size of beaches must begin by understanding the depths, velocities, and sediment-carrying capabilities of various flows in a beach area. One of the critical tasks in this case would be to develop hydraulic relationships at a transect site representative of beach areas.

Figure 13. A transect being conducted on Alaska's Gulkana River. Transect data can be used to determine which flow would provide a depth suitable for boat passage.

Hydraulic Geometry, Recreation Values, and the Manning Equation

Suppose a river has opportunities for camping and boating and you want to know how flows affect these recreation outputs or activities. Taking a simplified case, assume that on the low end you want to know the point at which the flow is too low for a boat to pass through a riffle, and at the high end you want to know when the flow is so high that beaches are inundated and camping is no longer possible.

One way to get the answers would be to measure flows in the field through the full range of flows. With enough observations and the right timing, you would eventually be able to identify the required flows, but this work would be both costly and time-consuming.

The alternative is to use hydraulic geometry relationships to estimate these flows, either based on existing gage data or a single set of cross section data collected in the field. For the sake of simplicity, assume that the critical boat passage riffle and camping beach are at the same location so the same "critical reach" can be used to explore both issues. A cross section or transect would be established at this location resulting in the channel diagram shown in Figure 14.

Rivers generally show predictable increases in width, depth, and velocity as flow increases (Leopold and Maddock, 1953). These relationships, called "at-a-station hydraulic geometry," can be developed directly from repeated stream gage measurements, or they can be estimated indirectly from a single set of cross section data using a hydraulic formula such as the Manning Equation. The Manning Equation shows the relationship between depth, flow, velocity, cross section area, and wetted perimeter. It is thus possible to specify a minimum depth for boating (the depth when a boat can pass without grounding) and identify the flow when this depth occurs, or choose the point on the profile (and its corresponding flow) above which the beach is too small for camping.

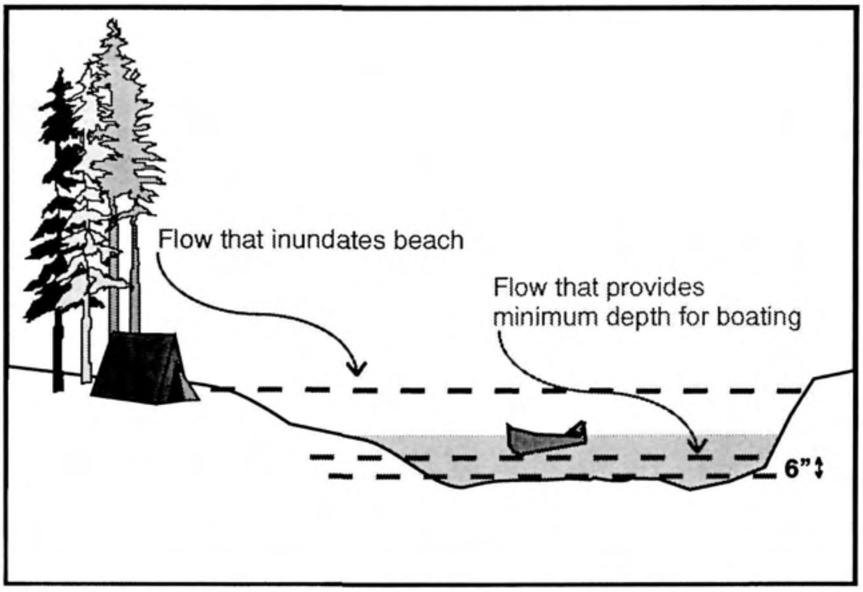

Figure 14. Simplified case where hydraulic geometry modeling can be used to identify flows that provide minimum depths for boating or that would inundate camping beaches.

LANDSCAPE POSITION AND RIVER CLASSIFICATION

Rivers are integral parts of the landscapes through which they flow. When describing river systems it is important to understand and identify the interdependency between rivers and their valleys. For example, is the river actively downcutting? Does the river flow through alluvial sediments where the channel is seasonally being reworked by sedimentation processes associated with various flow regimes? Is the river relatively unconstrained (e.g., the floodplain is several times greater than the bankfull channel) or is the river channel largely constrained by bedrock or human-built structures? Is the stream flowing through old valley- bottom lake deposits or other formations created by pre-historic geologic processes? The answers to these or related questions are at the heart of many long-term or indirect changes that may occur when a streamflow regime is changed.

Accurate descriptions of the landscape setting and geologic conditions are useful for understanding river conditions on almost any type of river, but this information is particularly important for examining geomorphic features that result from ongoing sedimentation processes. Depositional features such as riffle substrate, bars, beaches, and floodplains may represent critical components of overall stream character and they are often highly sensitive to changes in an instream flow regime. Depositional features are, by definition, pervasive and important on alluvial streams. In addition, they can also be prominent in bedrock or boulder streams, forming critical fish or wildlife habitats in backwaters or eddies and providing features important for recreation. For example, while the Colorado River in the Grand Canyon is a downcutting, geologically-controlled river, bars and beaches created by eddy flow in backwaters are essential components of the riparian ecosystem and provide high quality camping areas for recreationists.

There are several methods of river classification, all of which convey considerable information on river conditions and associated fluvial processes. For example, at the most basic level rivers can be characterized as either bedrock or alluvial, providing a starting point for information about the general character of a stream over a range of flows. However, rivers can be further classified based on the principal mode of sediment transport, landscape position, or other variables. For a brief discussion of these classification systems, see the sidebar on page 23.

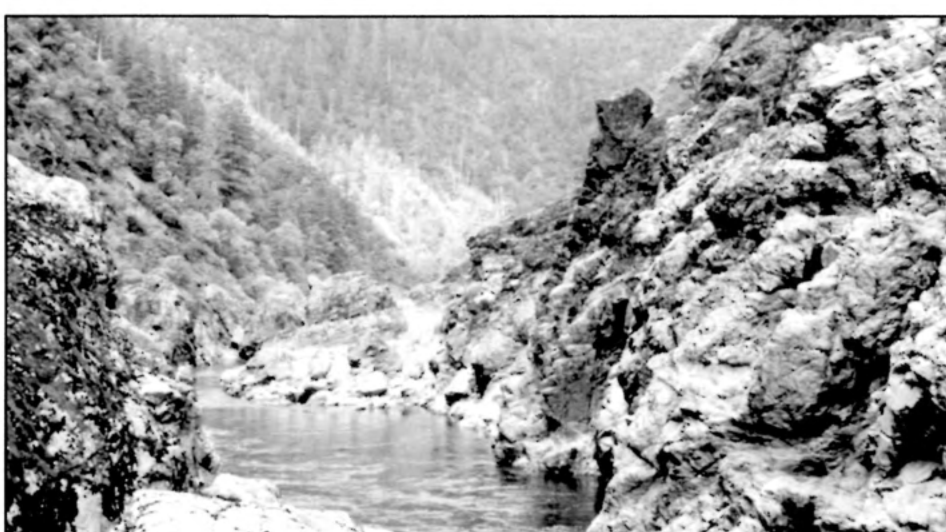

Figure 15. A bedrock channel reach on Oregon's Rogue River. Flow changes are unlikely to have large effects here, although other reaches feature flow-sensitive bars and beaches.

Classifying River Channels

Schumm (1977) has classified rivers as bedload channels, suspended-load channels, or mixed-load channels. Bedload channels transport greater than 11% of their total sediment load as bedload. They generally are straight-to-sinuous, have high width-to-depth ratios (>40) and fairly steep gradients. Conversely, suspended-load channels transport less than 3% of their total sediment load as bedload. They have high amounts of fine sediments (silts and clays) in their channel beds and banks, low width-to-depth ratios (<10), and typically have low gradients and high sinuosities. Mixed-load channels are intermediate between suspended load and bedload channels in their characteristics. Simons and Li, Associates (1987) further classify bedload channels as sand-bed or gravel-bed channels, because of the differing influences those bed types have on sediment transport. Schumm's classification permits an analysis of how a channel will respond to altered flows.

Figure 16. Example of an alluvial-type channel on Alaska's Deshka River. Changes in flow have larger effects on these kinds of channels.

Rosgen (1985) has also developed a stream classification system based on descriptors of hydraulic geometry, and existing channel characteristics. Rosgen uses the variables of watershed position, stream sinuosity, gradient, bed materials, cross-section width and depth, valley confinement, channel entrenchment, and depositional features to group streams into five major classes and more than 20 different sub-classes. The major classes are derived primarily from landscape position, ranging from steep headwater streams to deltaic streams. The sub-classes are derived from sinuosity, width-to-depth relation, bed-and-bank material composition, and so forth. Rosgen's classification may help in generalizing the results of site-specific studies to other reaches or other rivers.

An important aspect of many instream flow studies is to interpret the effects of alternative flow regimes on river form and process. This is a difficult issue for which there are generally only descriptive rather than quantitative tools. Where available, historical aerial photographs over several time periods can provide an excellent perspective for understanding the types of channel changes possible and expected. In some instances, physical modeling may offer a way to explore potential channel changes under different flow regimes at specific sites. However, these or similar analyses will not always provide enough information to accurately predict the way a river will change in response to various flows or sediment inputs. Nevertheless, accumulated knowledge about these relationships will often allow scientists to forecast the direction and perhaps the general magnitude of channel responses to flow or sediment changes.

Rivers flowing through fluvial-deposited sediments are the most susceptible to flow regime changes – especially changes in high flows. In contrast, bedrock channels generally experience little change in channel morphology regardless of flow regime.

When conducting an analysis of channel morphology response to different flows, it is useful to employ several different tools. First, the effect of alternative flows on sediment balances needs to be assessed. Next, based upon channel classification and river morphology responses to changes in flow or sediment, an assessment should be made as to overall morphologic response to changed flow and sediment regimes (see sidebars on pages 27-29). Finally, a deductive assessment of how individual morphologic features, such as bars, respond to altered flow and sediment regimes may be required.

Because of the complexity of flow and sediment transport interactions, an assessment of sediment balance response typically needs to be made on a case-by-case basis. Large dams both reduce sediment transport capacity and eliminate sediment delivery from upstream areas. This usually results in an excess of transport capacity immediately downstream from dams, downcutting channels, and an increased rate of erosion of depositional features. However, further downstream, if tributary sediment inputs are great, the now-reduced transport capacity of the mainstem may be overwhelmed by tributary sediment which might in turn accelerate sediment aggradation (the filling-in of the channel). Similarly, stream diversions tend to reduce sediment transport capacity in relation to sediment load, increasing sediment storage in depositional zones along a particular reach. One useful conceptual tool for understanding these relationships is the sediment/water scale shown in Figure 17. Any change in one parameter changes the others as well.

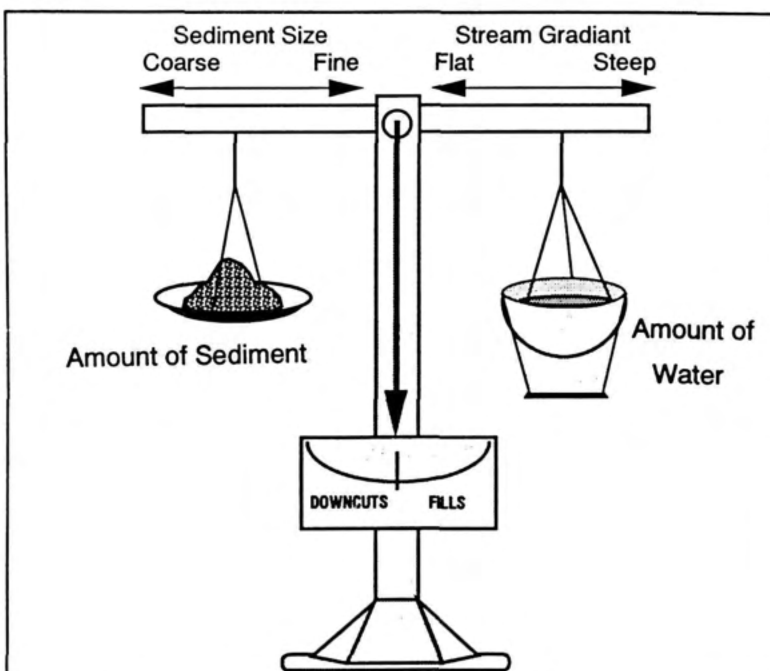

Figure 17. The sediment - water scale showing relationships between sediment inputs, flow inputs, and channel change. The balance between flow and sediment inputs determines how a channel will evolve.

How River Environments Respond to Changes in Flow

Indirect effects of flow play important roles in creating and sustaining high quality recreation experiences although it is often difficult to predict how changes in flows will change the river environment. Two examples of how changes in flow regimes may affect important features are given below.

1. Sustained Decreases In Flow

A sustained decrease in flow throughout a year or season is a common situation with rivers across the country as water is diverted for municipal water supply, industry, or agriculture. But what are the likely or possible effects of decreased flows? Table 3 provides a list of possible effects for Beaver Creek, an alluvial river in Alaska, where researchers explored these effects. If there were to be a sustained decrease in flows on that river, a number of *important physical features would change and thus affect the recreational opportunities on the river.* A few of the more important changes include decreases in size of gravel bars or beaches (detracting from camping opportunities which depend on open bars for good views, fewer insects, and ease of access to the river), loss of sloughs and the filling of pools (both of which provide important habitat and good fishability for arctic grayling, the principal sport fish on the river), and the increase in riffles, thus creating more critical reaches for navigation during low flow periods.

Readers should note that non-alluvial rivers, and even some alluvial rivers, may react somewhat differently than is shown below. In fact, the Beaver Creek conclusions are hypothesized rather than observed changes (there has been no decrease in flows on the river). The point is that there are a myriad of factors involved in how rivers adjust to new flow regimes. These are simply descriptions of the common changes one might expect; the goal of an instream flow assessment is to determine whether these will hold true as well as estimate the magnitude of them for given decreases in flows.

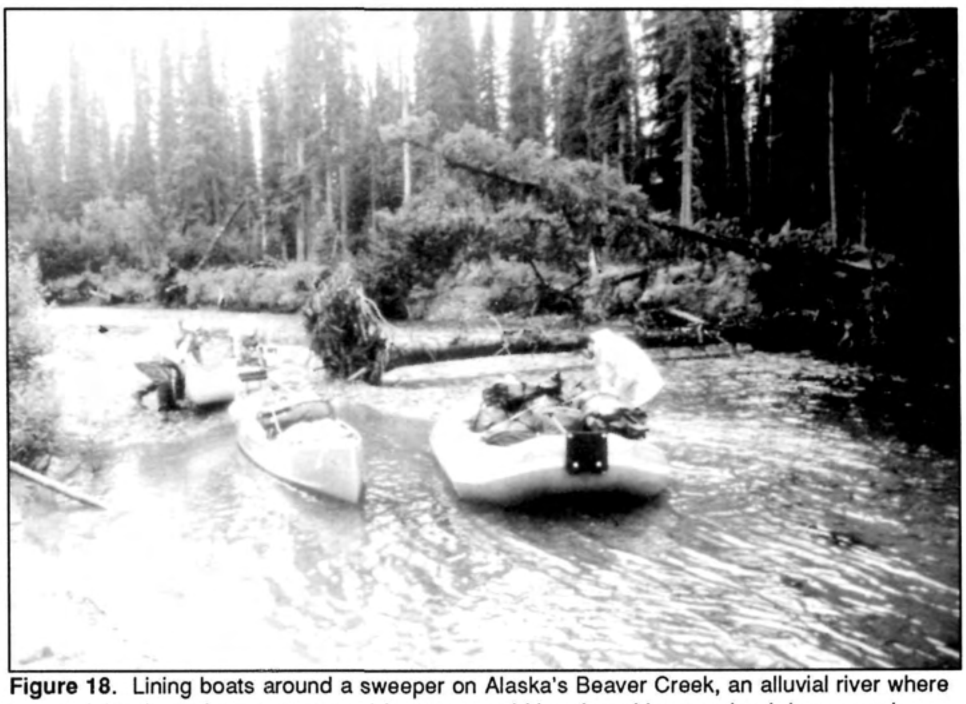

Figure 18. Lining boats around a sweeper on Alaska's Beaver Creek, an alluvial river where many of the river's important natural features would be altered by sustained decreases in flow.

Table 3. Possible river morphology adjustments caused by sustained decreases in flow on Alaska's Beaver Creek.

Feature	Adjustment	Comments
Average width	decrease	hydraulic geometry relationships
Average depth	decrease	hydraulic geometry relationships
Meander length	decrease	hydraulic geometry relationships
Gradient	increase	hydraulic geometry relationships
Pools	fill	Heede (1976)
Point bars/beaches	decrease in size	stream tries to increase efficiency
Riffles	increase in number	stream tries to increase efficiency
Width/depth ratio	increase slightly	hydraulic geometry relationships
Bank stability	increase	lower stress on high banks
Velocity	decrease	hydraulic geometry relationships
Sloughs	decrease	less adjustment and rejuvenation

2. Loss of Peak Flows

Another classic case of an altered flow regime comes with the development of a large upstream dam and storage reservoir. Most significantly, this creates a loss in peak flows as well as a loss in sediment, each of which can cause a number of morphological or vegetational adjustments.

The Bill Williams River in Arizona provides a useful example (see Figures 19 and 20). The initial result of the development of an upstream dam was severe downcutting of the channel immediately downstream due to the lack of normal sediments. In addition, there was significant aggradation (channel choking) much farther downstream as tributaries deposited sediments that the decreased main stem flows no longer had the ability to move. Both kinds of changes can have important implications for recreation on similar river systems. In particular, the downcut areas may lose beaches for camping or picnicking while the aggraded areas become choked with sediment and may become unboatable. Impacts on the fishery can also be significant, as the sediment loading areas may smother spawning or rearing habitat or cause declines in macroinvertebrates upon which fish feed.

Figure 19. Downcutting below the dam on the Bill Williams River, Arizona.

Figure 20. Channel choking downstream of tributaries on the Bill Williams River.

Exploring the Flow - Environment Relationship in Grand Canyon

The Colorado River in Grand Canyon provides a third example of how an altered flow regime can have significant impacts on the river environment. Glen Canyon Dam, just upstream of the Canyon, was authorized on the basis of its ability to control floods, deliver water for irrigation, and generate hydroelectric power (particularly peaking power). In meeting these goals, however, dam operations apparently affected several natural and recreation resources downstream. In recent years, environmental advocates have become increasingly concerned about those effects and federal agencies are in the process of completing a series of comprehensive studies to quantify what is happening as a result of current dam operation, as well as what is likely to happen in the future under different operating regimes. Costing several million dollars, the size of the effort helps suggest the complex and controversial nature of the issues. There may not be any single or simple flow regime that will provide for all desired outputs. Some of the more interesting natural resource questions being explored in the studies include:

- Are daily flow fluctuations (to produce peaking hydropower) contributing to beach erosion? Has the loss of spring floods created a situation where beaches are no longer rejuvenated? Can periodic high flow releases be designed to optimize beach rejuvenation?
- Has the lack of floods caused river banks to become more "stable," thus allowing riparian vegetation to encroach upon areas that were previously open beach? Has the new flow regime allowed establishment of new and different types of vegetation, thus favoring wildlife species not present in such numbers before?
- How have the less turbid waters from the dam affected aquatic species? Is the introduced trout fishery (which survives because of the colder temperatures) outcompeting native fish species such as humpback chub? Are the fluctuating flows from the dam stranding fish?
- Have the newly established fisheries had effects on other wildlife in the Grand Canyon? For example, bald eagles may benefit from the new trout fishery.
- Has the loss of spring floods and associated deposition allowed tributaries to expose and erode significant archeological sites?

Figure 21. A beach in the Grand Canyon of the Colorado River. Flow changes from Glen Canyon Dam have had a number of implications for the river environment.

Grand Canyon studies have also explored flow needs for rafting safety and challenge, and a comprehensive Environmental Impact Statement on how to operate the dam will include a variety of alternatives that integrate different flow needs for different resources. However, the effort is particularly noteworthy because of the extensive work on how flow changes have affected the long-term environment which is also critical for high quality recreation.

RIPARIAN VEGETATION

The importance of riparian vegetation for influencing channel stability and form, bank characteristics, floodplain processes and others is becoming increasingly recognized. Similarly, a shift in hydrologic regime that decreases the frequency and magnitude of peak flows can have a major effect on the composition and characteristics of riparian plant communities. Changes in hydroperiod (i.e., the length of time that riparian soils are saturated) due to dam operations or stream diversions may have important implications for the establishment, growth, and succession of riparian dependent plant species.

Although suppression of peak flows may provide improved bank stability, the loss of incremental channel changes during high flows may potentially eliminate plant species that are dependent upon high flows. For example, gallery forests of cottonwoods along many western streams may be slowly eliminated where peak flows have been suppressed or channels have been structurally stabilized.

The ability of streamside vegetation to influence water quality and channel processes is highly varied. It may include, for example, stream shading by overstory canopies (thus affecting stream temperatures), seasonal leaf and litter inputs (a source of biotic energy for many instream invertebrates and other aquatic species), bank stability associated with the occurrence of root systems (particularly woody root systems), improved fish habitat from the recruitment of large woody debris, altered nutrient cycling, increased channel roughness during overbank flows from above-ground portions of plants (i.e., stems and leaves), and others. Many of these changes are closely associated with a variety of recreational values (campsite quality, aesthetics, etc.), and it is also important to consider the long-term implications of altered flows on the ecological integrity and characteristics of riparian plant communities.

Figure 22. Riparian vegetation on Arizona's San Pedro River. Flows often play a critical role in determining the type and abundance of vegetation, which in turn can affect other resources.

A FINAL COMMENT ON EXPLORING FLOWS AND RESOURCE CONDITIONS

Preceding sections of this chapter have briefly explored how different flow regimes can affect resource conditions. As the discussion should have made clear, many of these effects are longer term and may be difficult to understand and document. Faced with such complexity, it is all too easy to ignore or pass lightly over the subject.

In the classic case, researchers may list the important functions of certain flows (usually floods), but then note that no one has been able to quantify these flow needs on the river in question. In the absence of this information, they then go on to recommend a bankfull flow (the one or two year flood) for a period of a few days to a couple of weeks every year or two to play it safe.

There is nothing inherently wrong with this approach, which has some validity for almost any river. Nearly all natural rivers have evolved with periodic flooding and only the most naive believe that floods are always a destructive natural force. Like many western forests that depend upon natural wildfire for their rejuvenation, many rivers (or sections of river) require floods to sustain their natural features. The issue, then, is less about whether some kind of riparian or channel maintenance flow is needed, but how large those flows should be, when they should occur, and what will happen if they are not provided.

The stock recommendation of a weeklong bankfull flow every year may make a good starting point for this discussion, but in many situations a closer look is warranted. For many rivers, a "bankfull" flow is insufficient to engage most fluvial adjustment processes. For other rivers, especially those immediately downstream from dams (and therefore "sediment-starved"), prolonged periods of high flows may further diminish sediment dependent resources. A major decision facing instream flow researchers is deciding when the services of hydrologists, geomorphologists, or riparian specialists are necessary to explore these sorts of issues.

The brief presentations in this chapter do not provide readers with the all the tools to conduct in-depth studies on the indirect effects of flow. They do, however, provide some guidance on when those studies should be conducted and what they need to explore. For example, it should be clear that it is more important to examine these issues on heavily regulated streams (those with larger dams, diversions, or withdrawals) than those which experience more natural variation in flows (streams with run-of-the-river hydropower or smaller diversions). Similarly, rivers with important alluvial features such as beaches, bars, gravel riffles, and sloughs are at greater risk of channel changes as a result of modified flow regimes than rivers or river segments that are have more bedrock channel features; studies are thus more important on the former. Finally, rivers that feature riparian vegetation dependent upon the river (e.g., arid western streams with their cottonwood groves) deserve a closer look than rivers where the riparian vegetation is virtually indistinguishable from the upland vegetation.

The heart of the matter is an explicit determination of whether various channel or riparian features play an important role in providing high quality recreation on the river, and whether a change in flows seems likely to result in significant changes to those features. If the answer is obviously "no," studies need only state this argument and move on to other issues. If the answer is "maybe" or "yes," further investigation by qualified scientists is warranted.

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Notes:

Chapter 5
EVALUATING FLOWS OR RESOURCE CONDITIONS

There are several ways of collecting evaluative information about flows or conditions. Choosing among these methods depends on a number of factors, including the type of river, the recreation opportunities in question, the type and availability of users, and the amount of time, staff, and money one can spend on the study.

This chapter categorizes and reviews the variety of evaluation methods and/or criteria currently used in research. Recognizing the impossibility of fully explaining each method, the goal is to identify basic concepts, assess relative advantages and disadvantages, and suggest the keys to applying each method successfully. At the end of the chapter, a summary section reviews the key issues in choosing among the various methods. Much of the material in this chapter has also been discussed in a technical paper on streamflow and recreation (Shelby et al., 1991). Readers with greater interest in these methods and the places where they have been applied should consult that paper.

Readers should also note that most studies utilize a combination of methods; no single method offers all the answers. In addition, some methods are more narrowly focused -- a way of answering a specific question -- while others are more comprehensive and provide an approach to answering several questions. When combinations of methods are particularly useful, this is noted.

As discussed in Chapter 3, it is often easier and more direct to evaluate flows than resource conditions (e.g., when whitewater boaters are asked about flows rather than the size of hydraulic reversals (holes) or standing waves). In other cases, however, evaluations will center on resource conditions such as the type of vegetation or size of camping beaches, and researchers also need to be able to trace those conditions back to the flows that generate them. The techniques involved in developing relationships between flows and conditions were presented in Chapter 4. In this chapter, the focus is on evaluating flows or the effects of flows. Readers should also note that while many methods presented below tend to focus on the direct or short-term effects of flows (such as hydraulics or the shape, depth, or velocity of water in the river), it is possible and important to apply them to long-term or indirect effects as well. Scientists may be able to discover how flow changes will affect a river's environment, but it is also critical to evaluate whether those changes are acceptable or not before deciding on appropriate flows.

HISTORICAL USE METHOD

With this method, information about the intensity of recreation use on a river is correlated with flow levels at the times when use occurred. If use has historically occurred at a particular flow, that flow is considered adequate. Output from this method is typically expressed as a range of acceptable flows, with the low and high ends defined by the lowest and highest flows for which use occurs. In some cases, the logic of this method is extended to define an optimum flow as the flow when use is at its highest levels.

Advantages and Disadvantages

This is a potentially quick and easy method which shortcuts many of the steps presented in this handbook. If good use data is available for a resource, it can provide some insight. However, like most easy techniques, it has significant limitations.

Most importantly, this method rests upon a pair of suspect assumptions. First, it assumes that users will only take trips when flows are adequate. In fact, people have multiple motivations for taking a recreation trip, and the absence of good flows does not necessarily mean that users won't go. Second, the method assumes that if good flows are available, users will take trips. But any number of other reasons may prevent users from taking trips. In the Pacific Northwest, for example, there is no shortage of good flows throughout the rainy winters, but use is often higher during the spring and summer when flows are less advantageous but the weather is better. There simply may not be a good correlation between flows and use.

Figure 23. Historical use data can help researchers identify a range of flows acceptable to users, but the method has several limitations.

Another major problem is that good use data are often difficult to find. While almost any managing agency collects use data, the data are often too coarse. In order to execute this method well, you need daily use information disaggregated into the different types of use (each of which may have different flow needs). Few resource managers have this kind of information available.

Other problems with this method include its inability to examine flow needs for potential opportunities (e.g. flow needs for boating in a by-pass channel that a dam has kept dry for 50 years), the inability to develop incremental flow relationships (it simply provides a range of acceptable flows), and its total lack of information on long-term flow needs to maintain or create riparian or channel features important to recreation opportunities.

Keys to Success

Successfully using this method requires careful collection and application of use data. Data is most valid when verified from multiple sources and checked for reasonableness by interviews with longtime users or resource managers. In fact, these people can often provide more useful information about use than data from mechanical counters or registers, even though the latter are more quantitative.

Summary

This is a useful method for getting a quick feel for certain flow needs and may lead to a legitimate determination in some specific situations, particularly if the resources for larger studies are not available. This method, however, offers no information about the quality of recreation experiences and is based on potentially misleading relationships between use and flows.

As a stand-alone method, this technique has major limitations. As a scoping element in a more comprehensive study, however, it can prove useful. Information about use and the seasonality of that use should be examined during the resource assessment stage of any study, and by associating a range of flows with seasonality, researchers can get a feel for the range of flows to explore in greater detail. This preliminary determination is particularly helpful for suggesting sampling frames for survey efforts or choosing good times of the year for resource reconnaissance (field trips by the study team).

PROFESSIONAL JUDGMENT METHODS

This refers to a variety of techniques that have in common the use of a resource specialist who makes reasoned flow need estimates from short but strategically conducted resource reconnaissance and an accumulated general knowledge of the issues. These methods are best used to explore indirect impact issues associated with river geomorphology or riparian changes, although they can also be used to examine direct impact issues such as navigation, whitewater, fishability, or aesthetics. These methods are often used to check the reasonableness of results from other analyses as well.

Output from these methods can come in a variety of forms, although they tend to lean toward descriptive rather than quantitative presentations, particularly for geomorphic or riparian issues. These methods often begin and end with a single-visit to the resource (judgments based on multiple visits usually focus on other methods and do not strictly fit in this category). In many cases, the judgment is not made in an obviously systematic manner, but there is no reason the approach could not be applied in more methodical ways to show explicit links between various assumptions, on-site observations, and final recommendations.

Researchers could also develop more quantitative output such as incremental curves, even if they are based on reasoned judgments alone.

Advantages and Disadvantages

These are potentially quick and easy methods because they typically involve few staff and limited on-site work (reconnaissance conducted with this method would not include large scale or systematic data collection). They are also relatively defensible in legal environments where the testimony of experts is highly regarded (although readers should note that the testimony of one expert is often easily countered by the testimony of another). Ultimately, however, these methods also have limitations because several critical issues are addressed by educated guesswork rather than hard data.

Professional judgments involve subjectivity, and they rely on the ability of researchers to make judgments about users' preferences or the impacts of different flows on various conditions. If those judgments turn out to be wrong, subsequent flow recommendations will be poor.

Keys to Success

The success of studies using professional judgment methods depends on at least three factors. First, the professionals making the judgments need to be of the highest quality. In addition to experience and skill with the issues at hand, high quality researchers are those who invest themselves in the resource they are studying to become familiar with the needs of the river and its recreation users. Professional judgment methods, more than any other, rely on the intelligence, integrity, and attention of the researchers.

Figure 24. Professional judgments are a part of any study, but studies based on judgments alone have significant limitations.

Second, the thinking that goes into making judgments needs to be as explicit as possible. Judgments will have a higher degree of replication and defensibility if researchers are clear about the principles and assumptions upon which their judgments are based. Some degree of subjectivity and intuition will always play a part in the process; however, the goal is to make these elements explicit. The formation of interdisciplinary teams and frequent conferencing is one technique that can help in this regard (see sidebar on page 36), forcing researchers to explain their thinking to other thoughtful people who may see things from a different perspective. Employing a process as described in this handbook is another useful technique, helping provide a structure for tracking assumptions, observations, and judgments.

Third, because on-site observations are at the heart of many professional judgments, the timing of resource reconnaissance is critical. Fieldwork should ideally occur at a variety of flows (and in the best situations flows will actually be manipulated for the purposes of the study). When it is not possible to see a full range of flows, researchers should plan field work when flows will be near-marginal (when small changes in flows are having relatively large impacts on the resources in question). In either case, observations at the river need to be efficiently conducted and well documented. The sidebar on fieldwork (page 39) examines some simple ideas that can improve those aspects of a study.

Summary

Some form of professional judgment is a part of any study (and a major component of others), but as a stand-alone approach this method is most appropriate for the indirect impact issues associated with geomorphic and riparian changes. This method is also useful for direct impact issues when there is a limited time schedule or limited budget to conduct the study, although the validity of these results is clearly lower than if other data were generated.

The quality of professional judgment methods can be enhanced by some survey-based methods such as interviews and focus group meetings, and they also combine well with transect-based methods (all of which are discussed later in this chapter). In each of these cases, the final recommendations will still be developed by the researcher, but they will be more broadly based.

Developing Effective Interdisciplinary Teams

Most instream flow research strives to be inter-disciplinary in nature; in reality most studies tend to be more multi-disciplinary with specialists focusing on their sections rather than the comprehen-sive package. This lack of coordination and exchange can be a major problem; avoiding it requires continued effort. A few suggestions on ways to develop and maintain effective interdisciplinary teams:

Figure 25. Structuring communication and interaction among team members is critical for making studies interdisciplinary rather than multi-disciplinary.

- ❑ Establish clear interdisciplinary objectives at the outset of the study to ensure team members focus on the larger research goals.
- ❑ Carefully consider the make-up of the study team to find researchers who are willing and able to work together. Interdisciplinary research is a collaborative effort; team members need to be able to work well with others. Personalities and attitudes often matter as much as experience and brainpower.
- ❑ Establish a strong team leader to structure the effort and resolve potential differences between team members. As with any leader, fairness and decisiveness are essential characteristics.
- ❑ Structure communication and interaction during the course of the effort, particularly during fieldwork. Although there are significant costs involved, it is extremely important for researchers to spend time together at the resource as well as at formal team meetings to discuss findings throughout the study process. Our experience suggests that most major study innovations or critical conclusions occur as a direct result of team interaction. Having to explain or defend ideas in front of a group of critical observers is essential to good research.
- ❑ Encourage discussion and exchange among team members even when they are speaking outside their field of expertise. Too much scientific research today pretends to be specialized and too difficult for non-experts. In fact, researchers from outside a field of expertise often have very constructive comments.

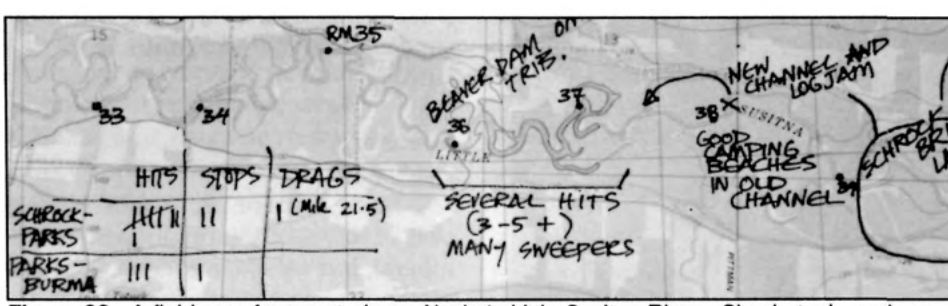

Figure 26. A field map from a study on Alaska's Little Susitna River. Simple tools such as this can make field work vastly more useful (see sidebar on page 37).

Conducting Effective Resource Reconnaissance

While fieldwork is an essential part of most instream flow studies, professionals usually face limitations in the amount of time they can spend at a river. As a result, when researchers do get to the river they need to make the most of the trip. The tools and techniques we have found useful in conducting fieldwork effectively are listed below. Although these suggestions may seem obvious to seasoned professionals, it never hurts to have a checklist.

- ❑ Take both video and still cameras. Even researchers with good memories or note-taking skills may be unable to recall details that become evident through photographic media. Video is particularly useful because it allows the researcher to verbally add information about what is being shown. Slides are also important. Most reports will be vastly improved by photos showing critical reaches or the effects of different flows on users' trips. Make sure to date and place both media so the corresponding flows can be determined. Developing lists of places and/or issues to photograph prior to the trip can be useful as well; it is easy to become preoccupied with other chores while in the field.

- ❑ Prepare a waterproof large-scale topographic map prior to the trip and take along waterproof pens for easy notetaking (see Figure 26 on previous page). A series of aerial photos for the river may also be useful, particularly if the USGS maps are old (rivers sometimes change enough that you won't know where you are). Determine and mark river miles and gradients on the maps or aerial photos. Try to take notes as the trip goes along, or failing that, structure note-taking breaks. In bad weather or on rivers where note-taking is difficult, consider a small voice-activated tape recorder. With the map in front of you, it is easy to make observations and associate them with a river mile.

- ❑ Have every member of the reconnaissance team keep a journal in addition to helping mark up the waterproofed map. Structure time during the trip for people to take notes and make general observations. Good professional judgments are only made after careful consideration of both immediate and long-term impressions; it will be difficult to remember the former without the help of some brief notes. A voice-activated tape recorder again offers an alternative way to record these observations without much effort on-site. Upon return to the office, of course, the tapes must be converted into written notes.

- ❑ Develop a "table of observations" for easy note taking in the journals or on the waterproof map. For example, if navigation is an issue, create a table with headings for "hits," "stops," "drags" and portages. As each event occurs, you can note it more easily. The point is to keep reminding yourself to take notes to make your observations more quantitative and reliable.

- ❑ If the fieldwork involves any larger-scale data collection efforts such as systematic inventories or hydrology transects, divide chores among team members prior to the trip. Transects and other tasks can take a lot of time but rarely require everyone's participation; unneeded people should move on to other tasks.

- ❑ If boating is an issue, try to take trips in the kind of craft that are typically used on the river. If people use different kinds of boats, researchers should attempt to use the full variety of craft.

- ❑ If fieldwork is conducted from a boat, take a paddle with measurements marked for quick depth checks.

- ❑ Take along a guide or someone who knows the river. While most recreation professionals get to know the resources they manage, it is unlikely they will know it as well as people who live or work on it. If veteran river users cannot be included as part of the fieldwork, structure time in the trip for simply talking with users you may encounter.

USER SURVEY-BASED METHODS

User survey-based methods involve techniques designed to solicit information from recreationists about flow-related conditions and their evaluations of those conditions. These methods are generally arranged along a continuum from interviews or focus group meetings featuring qualitative evaluations to more systematic, quantitative efforts associated with on-site or off-site surveys.

Survey-based methods are critical for exploring evaluations of flows or conditions. No other method provides such a quantifiable form of evaluative information. Users are the experts about factors such as the number of navigation problems that may be acceptable for a given trip, how much challenge or risk they prefer when running whitewater, and where or how they like to camp or fish or swim. Surveys are the means for collecting this information.

Output from survey methods can come in a variety of forms, ranging from the descriptive comments about preferable conditions to quantitative evaluations (usually in graphic form) of various conditions or the range of flows that create them. The greater the stakes or controversy, the greater the need to collect information from a statistically valid sample.

In the following sections, advantages, disadvantages, and keys to success will be discussed separately for each of the major techniques: interviews/focus group meetings, single or present flow surveys, and flow comparison surveys. Sidebars on "controlled flow assessments" (where users or resource experts evaluate a range of flows on a regulated river) and surveys involving photographic media are also presented, along with short discussions on survey theory (the concept of social norms) and conducting effective surveys. A summary for survey methods in general follows.

INTERVIEWS/FOCUS GROUP MEETINGS

Interviews or focus group meetings are the most basic of the survey-based methods; they generally provide descriptive or more anecdotal information about the best conditions or flows. They may be conducted on-site, when a purposive sample of users are brought to a river to run various flows and discuss the differences between them, or off-site during the scoping phase of an effort that will mainly rely on professional judgment. The key element that distinguishes interviews and focus groups from other survey-based methods is that information is collected from a smaller number of users and is not quantitatively oriented.

Advantages and Disadvantages

As a stand-alone method, interviews/focus groups often have limited rigor. The small sample sizes and lack of quantification means results are less defensible. However, these methods are generally cheap and easy to accomplish, and they can provide a powerful way to improve professional judgment efforts. In addition, in some situations (particularly on shorter river segments where controlled flows allow users to evaluate a full range of flows and conditions, also known as a "controlled flow assessments," see sidebar on page 42), the focus group technique often provides ample information. A focus group also allows identification of and interaction among representatives of key interests (such as boaters and anglers), which is a benefit in itself.

Keys to Success

Interviews and focus groups work best when they are relatively structured and creating a list of topics and questions to be covered in an interview or meeting is useful. With controlled flow field assessments (see sidebar on page 42),


Figure 27. Interviews with experienced users can provide useful information, although this approach lacks the rigor of more quantitative survey methods.

a diary or logbook format can also prove useful since the group will be experiencing several flows during the effort.

Interviews and meetings are generally most productive with experienced users of the resource. While almost any user may be able to provide good information about preferences for some flow-related conditions, many of these users are oblivious to other conditions, and very few can help the researcher associate good conditions with specific flows. Of course, when interviewing veteran users, researchers need to examine whether the conditions good for experts are likely to be good for inexperienced users as well. We have generally found experienced users to be astute observers of the conditions necessary for inexperienced users, but this may not always be the case.

In general, a larger number of people to be interviewed or included in the focus groups is better, providing greater verification for the ideas being discussed. However, in most situations interviews or meetings with more than a dozen diverse users adds little new information. On the other end of the spectrum, even a single interview with an experienced user can provide invaluable supplementary information for a predominately professional judgment-based effort.

Photographic media can also provide useful information to a researcher employing interview/meeting techniques, and slides or video taken by users should be examined if they are available. Pictures or video footage taken by the researcher may be useful to introduce during interviews or focus group meetings as a departure for discussion. Videotaping recreation activities during field assessment efforts is also useful, and tapes can be used to review, illustrate, and support group consensus about conditions and flows. For more information about using photographic media with survey-based methods, see the sidebar on page 42.

SINGLE FLOW SURVEYS

Single flow surveys, also known as present flow surveys, involve asking users at the river to evaluate the flows and flow conditions they just experienced. In order for the format to work, users need to be surveyed at a variety of flows. The primary difference between single flow surveys and the interview/focus group techniques described above is that surveys imply some formal quantification of user responses. The most elaborate efforts involve random sampling of users throughout a season to provide information about all user groups and flows. A well conducted controlled flow assessment (see side bar on page 40) may also utilize the format of this method, with participants filling out single flow surveys after each flow they have experienced.

Figure 28. Single (or present) flow surveys ask users to evaluate the flow and conditions they have just experienced.

Advantages and Disadvantages

This method provides greater quantification and more validity than interviews and focus groups, but generally costs more to administer in both time and expertise. Single flow surveys are typically administered on-site and thus require technicians to be available for a considerable amount of time and pay greater attention to the process of collecting and coding data. In addition, there are a series of issues to be resolved in developing a useful survey instrument (see sidebar on conducting survey research on pages 44-45).

Because they are administered on-site, single flow surveys generally don't allow as many questions as flow comparison surveys (see below), but they can allow the administering technician to help the user understand why it is important to participate, thus improving response rates and the defensibility of results. The technician can also help users better understand the kind of information researchers are trying to collect.

Controlled Flow Assessments

Upstream dams make it possible to study a range of flow levels over a short period of time. Although controlled flows require the cooperation of dam operators, this approach offers great opportunities to directly observe the effects of flow on recreation. Other methods in this chapter are distinguished by the way the **dependent** or response variables are assessed (through surveys, etc.). The controlled flow assessment is unique, however, because it manipulates the **independent** or causal variable, the amount of water in the river.

The idea is to arrange for a range of flows to occur during a relatively short period of time. At each flow, a group of participants is assembled representing the variety of activities, skills, and boat types under investigation. These individuals then express their evaluations of the desirability, advantages, and disadvantages of each flow. This can be done through informal discussion, structured discussion such as focus groups, formal interviews, or formal surveys (using both the single flow format after each flow and the flow comparison format after all flows have been experienced). The more structured formats allow collection of more quantitative information. For activities which take a relatively short time, it may be possible to experience the range of flows in a single day, although longer time periods have been used when necessary to accommodate the time required for activities or constraints on dam operations.

Controlled flow field assessments have been conducted on several rivers for a number of different boating and fishing activities. The earliest stuides were conducted on the Ocoee River in Tennessee and the Snake River below Hells Canyon Dam. More recent efforts have taken place on the Kennebec River in Maine, Oregon's McKenzie River, Wisconsin's Pine River, and the Farmington River in Connecticut/Massachusettes with several more planned for the near future.

All of these studies have provided outstanding opportunities to assess flow effects. Controlled flows insure that evaluators knew the exact flow levels, and they allowed participants to experience the full range of flows in a short enough time period to facilitate comparison. Careful selection of evaluators also helped assure representation of all relevant activities and interests. When controlled flows are a possibility, the approach is both efficient and effective. When combined with some of the more quantitative survey formats, controlled flow assessments are without peer.

For all their power, however, controlled flow assessments have some limitations that need to be carefully addressed. First, these assessments are generally only possible on shorter, more accessible rivers where participants can experience different flows over a relatively short period of time. It is difficult to have participants spend more than a few days at a river and on longer rivers it may take too much time for releases at a dam to change flows downstream. Second, researchers need to consider the effects of rapid changes in flows for the controlled flow study on other resources, particularly fish. A controlled flow study planned in 1992 on Oregon's North Umpqua River, for example, had to be postponed and modified due to concerns that the flow pulses would adversely affect the river's steelhead. One way to avoid this problem may be to have controlled flow releases mimic historical flow events, but the key in any case is to involve other resource specialists in planning the assessment. Many of these scientists may also be interested in using the controlled releases to explore effects on their resources. Finally, researchers need to carefully consider the make-up of participants in a controlled flow assessment; the generally smaller sample size means that strategic responses could bias results. In a recent study on the Farmington River, there were some significant differences among ratings of flows for fishing by local and non-local anglers (Land and Water Associates, 1992). A single flow survey was also conducted on the river for a season, and its findings agreed with the non-local anglers. In this case, local anglers may have strategically rated certain flows less favorably, perhaps because they knew those flows were better for boating, an activity with which they have some conflicts.

Figure 29. Controlled flow assessments provide a powerful way to evaluate several flows in a short period of time.

Single flow surveys eliminate some of the memory limitations associated with flow comparison surveys, and users do not need to be knowledgable about gage or flow readings or the conditions at other flows. However, the single flow survey focus on present flows does not allow users to tell about the full range of flows they may know about. Similarly, the focus on present flows also creates some difficulties for respondents. Users are being asked to rate something for which they may not have a baseline or standard; it is difficult to rate a flow without comparing it to other flows. Its a little like going to an exotic ice cream store, where several samples must be tasted before appropriate evaluations can be made.

A final disadvantage with single flow surveys focuses on the sample. In many cases, users asked to participate with these surveys are "average users" with relatively little experience or sensitivity toward different flow levels. Using the ice cream store analogy, they are people who like eating chocolate or vanilla, but lack strong feelings about more exotic flavors. Their ability to evaluate those other flavors may be diminished. These kinds of users tend to rate most flows as satisfactory unless flows are clearly inadequate. The more subtle differences may escape them.

Keys to Success

Successfully completing any survey requires significant care and experience (see discussion in the sidebar on pages 44-45.) With an single flow survey, there are at least three further issues for researchers to address. First, it is important to survey samples of users at a range of different flows, because questions ask only about the single flow users just experienced. This can be a problem in years when certain flows do not naturally appear, or if users do not recreate at particular flows. Second, it is important to ask questions about how recreationists use the river so you can aggregate responses for different groups. Important questions in this regard would focus on users' experience levels, differences in type of craft or recreation activity, skill level, etc. Finally, it is important to focus questions on flow and flow-dependent conditions in order to minimize the effect of other conditions on overall trip evaluations. In the absence of this focus, average users' evaluations may be influenced by other trip conditions such as the weather, social interaction, etc.

FLOW COMPARISON SURVEYS

Flow comparison surveys refer to surveys given to users who have recreated on the river several times and are sensitive to the flows and conditions that are best for their kind of trip. These surveys ask users about a variety of flows and conditions and are appropriate only when there is a knowledgeable user group for the river. While it is possible to administer a flow comparison survey on-site, in most cases these are administered as mail or telephone surveys. A special kind of flow comparison survey involving reactions to photographic media or written descriptions also fits in this category (see sidebar on page 42).

Advantages and Disadvantages

If users can specify their flow or condition preferences, there are a number of advantages with flow comparison surveys. First, although any well-conducted survey involves considerable effort and significant costs, off-site flow comparison surveys can be considerably less expensive than on-site surveys because they involve fewer administrative costs. In addition, they can be conducted at any time during a year, while single flow surveys need to be conducted during the use season.

Second, flow comparison surveys generally allow researchers to ask more questions than on site surveys. This is particularly important if you are trying to get information about a variety of flow conditions or possible flows, including those that may not be currently available (after a dam or diversion was built) but which were once well known.

Finally, flow comparison surveys allow users to specify preferences for a range of flows. With the single flow survey, users respond to only the single flow and its resulting conditions; with a comparison survey, researchers receive responses regarding a variety of flows.

There are a couple of disadvantages with flow comparison surveys however. First, respondents need to be knowledgable about the

Surveys Involving Photographic Media

Photos, video sequences, or even written descriptions of various flow-related conditions offer another way to determine users' evaluations of various flows. A kind of flow comparison survey, the sample is shown representations of the river at different flows and asked to evaluate them. The method is also a little like a controlled flow assessment, although users experience the flows vicariously rather than in person.

Figure 30. Lower Falls on the Yellowstone River. Having users rate photographs of different flows is a useful method for exploring aesthetics issues.

The technique has been used in a number of studies. The most common studies have users rating the scenic beauty of a waterfall or creek at different flow levels, but some studies have had kayakers, anglers, and shoreline users rate different flows for their activities as well (see Shelby et al., 1991 for a review).

The use of photographic media to represent flows is an innovative way to explore user evaluations. Current research suggests that these media, and particularly video, can be used to accurately depict conditions and allow users to make defensible evaluations. However, there are a number of issues that need to be carefully addressed for the method to be employed successfully, and in some cases even properly conducted efforts may fail to provide as useful data as on-site survey work.

One issue is choosing appropriate locations for shooting the images, as well as composing good quality scenes that appropriately focus on flows and their effects on scenic beauty, boating quality, or other attributes in question. Oblique views of rivers from scenic overlooks, for example, tend to "flatten" perspectives and may minimize differences beween flows. Similarly, scenes that emphasize canyon walls or vegetation may distract respondents from evaluating the subject of interest, flows. Boaters rating the boatability or quality of whitewater may also have difficulty rating a scene unless boats and boaters can be seen in the images, and even then the images can easily be misinterpreted. Watching someone run a rapid is simply not the same as being in the rapid. Ideally, researchers will want to present images from the perspective of the user, but the best images may require use of telephoto lenses, polarizing filters, low angle composition, or other similar "tricks." Having said that, it is also important to make sure that all scenes at a specific location are photographed in a consistent manner. It would hardly be a fair evaluation to have some flows at a location presented up close while others at the same location are presented with a wider angle. Likewise, it is important to try and make all other elements in the image (aside from flow) equal. Images to be compared should be shot at the same time of the year, and ideally under similar weather conditions. Recent advances in digital imagery technology may offer improved ways of addressing many of these issues.

Another issue concerns instructions to respondents and survey analysis. Researchers conducting more complex studies on aesthetics of different flows have purposely avoided having respondents focus on flow during evaluations, and they have utilized complicated psychophysical analyses to factor out influences from other natural features. In other cases, this level of analysis may be unnecessary, and respondents are simply asked to rate scenes or choose between paris of images. Regardless of the approach used, the ultimate goal is an interval scale measure of scenic or recreation quality for each scene and flow.

A final issue concerns the influence of sound associated with video media. Both sound and motion are important components of flow aesthetics; their importance makes a strong case for the use of video over the use of slides. However, at least with the case of sound, some control and consistency is necessary for appropriate user evaluations. Ideally the sound presented to respondents should be proportional to the sound they would hear on site. Some studies have used decibel meters to ensure quantitative data about sound levels at different flows, but the point is to simply be consistent in how volume is used when representing the scene.

Social Norms

The ideas that have come to be known as normative theory are among the most enduring in resource management, providing a useful way to conceptualize and organize information about people's evaluations of conditions or behavior. The theory is simple. Individuals have a personal norm, or internal standard, by which they evaluate the appropriateness of a certain condition or behavior. If asked (as through surveys), individuals can often specify this norm. Taken together, aggregate personal norms (usually represented as a curve based on the average of personal norms) can then be used to represent the social norm or group standard. When applied to the instream flow issue, normative evaluations generally refer to group preferences for certain flow conditions or the flows that create them.

Because they are empirically defined, social norms have a number of measurable characteristics, including: norm intensity (how strongly a norm is held by a group); the range of tolerable conditions; minimum, maximum, and optimum conditions; and norm crystallization or the level of group agreement. Figure 31 represents a social norm as it might be applied to an instream flow evaluation for recreation. The curve represents the average rating of recreation quality for each flow among respondents in a sample. Norm crystallization, or the level of group agreement, is defined as the standard deviation about the mean for each point on the curve. As represented in this graph, a social norm is the same as a flow preference curve, although the latter may be developed by non-survey methods as well.

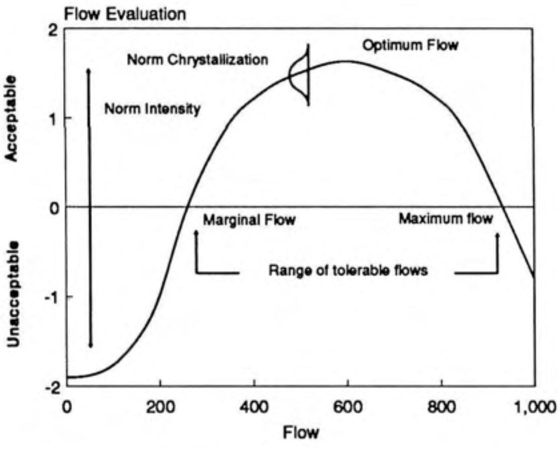

Figure 31. Example of a social norm curve and norm characteristics for hypothetical instream flow evaluations.

The key to successful use of the social norm concept is understanding its empirical nature. As long as people can specify their personal norm, social norms can be represented as aggregate personal norms. However, this does not mean that social norms are always strongly held or widely agreed upon. These issues must be addressed through an examination of the data. Using accepted methods of data collection, analysis, and presentation, it is possible to fully understand the intensity of agreement about a social norm, thus providing better basis for various management decisions.

flows they are rating: they have to have experienced the range of flows in question and know it when they did. In many cases, recreationists use gages or flow information that may be inaccurate and so the evaluations carry this inaccuracy as well. In other cases, recreationists may not correctly recall the conditions or flows they experienced. Second, there is the issue of "conventional wisdom" and the bias it introduces. On many rivers a traditional flow range may be established and it gets repeated in the survey even if the tradition is falsely based or no longer relevant (as boater skills, equipment, or the river itself changes).

Keys to Success

As discussed for single flow surveys and in the sidebar on surveys (page 42), any well-conducted survey requires considerable attention and effort. In addition, there are a number of other factors critical to conducting a successful flow comparison survey. Most importantly, researchers must be sure they have a group of experienced users from which to sample. People who have only been to a river a few times rarely

Conducting Effective Surveys

To the uninitiated, surveys can seem simple and routine. Those who have had the pleasure of developing, administering, coding, and then analyzing a survey, however, know better. Conducting a survey is much harder than it appears, and conducting a high quality, scientifically sound survey requires addressing a number of complex issues. A brief discussion of some of those issues and ways to address them follows. When studies involve survey efforts, project reports should include information about each of these issues. For more information about survey research, see the references provided at the end of the chapter.

Sample Frame Development

Deciding who to sample and how to reach them are central survey issues. Because "average users" are generally not able to provide useful information about flow-recreation relationships, more experienced or veteran users need to be reached in a purposeful way. Samples in these cases are not strictly random or representative, and it is important to make the distinction. In other cases, surveys may be directed at users in general and a random sample is preferable.

Tracking down experienced users is a sometimes arduous task, although we have found that once you have tapped into a recreation community, these users become increasingly easy to reach. For heavily used rivers, it may be possible to survey or collect names of respondents at the resource. For lower use rivers, a mailed survey effort is preferable and may require an extensive effort to contact users by phoning around. A note of encouragement: this may not turn out as difficult as it sounds. Starting with a handful of known users for the Dolores River study, we were able to develop a list of a couple hundred within two days.

Sample Sizes and Response Rates

Choosing the appropriate sample size is another major survey issue. While the statistical reliability of survey results obviously improves with larger sample sizes, most researchers face budget constraints and want to pay for the minimum sample needed to support defensible conclusions. As a general rule of thumb, sample sizes of at least 30 (for each group of interest) are required for even basic statistical analysis, and sample sizes greater than 200 are good targets for more sophisticated analysis. Smaller samples can be used in some situations if there is strong agreement about the issues of interest. The more controversial the issues, the more important it is to have large, representative samples. It may be wise to consult with a statistics expert who can help calculate appropriate sample sizes for a given degree of confidence.

Response rates for well-conducted recreation surveys are generally high. It is common for on-site surveys to have response rates near 100 percent, and high quality mailed surveys often exceed 70 or 80 percent. Researchers should aim for these marks and, according to a recent study, probably should not worry about non-response bias unless rates are less than 65 percent. High response rates require a thorough, professional effort, including good survey design -- pre-tested questions, manageable questionnaire length, relatively interesting questions, ease in returning the questionnaire, and appropriate reminder letters and follow-up.

Question Development and Analysis

Developing good questions involves a combination of art and science. Although there are few set "rules" for developing good questions, there are a number of things which invariably improve their quality. First, it is critical to pre-test a survey. It is usually not necessary to pre-test a large sample of people, but holding a few focus group meetings to go over questions often results in a number of useful changes.

Second, standard question formats help make them easy to understand and answer. Multiple choice and Likert-type scale formats are generally preferable to ranking, fill-in-the-blank, or open-ended formats, although each of these may be appropriate in some situations.

Third, questions and the overall survey should be as simple and short as possible. Although interested users seem willing to work reasonably hard at answering questions no matter how tortuous the language, response rates will suffer among less committed respondents. As a rule of thumb, an on-site survey should be able to be completed in less than ten minutes, while a mailed survey should take less than a half-hour. A pre-test can help

Conducting Effective Surveys (Continued)

gauge whether the length and difficulty of questions are burdensome.

Fourth, some issues in a flow-recreation survey may be complex and should be approached from different angles. It may make sense to ask multiple questions about important issues, although it is useful to let respondents know when you will be doing so. Providing information about why certain questions are being asked is usually appreciated by respondents.

Finally, it is important to think about how the results from a question will be analyzed. We have found it useful to formally outline expected results and sketch out potential graphs or statistical presentations; these exercises will often uncover weaknesses in questions or response categories.

Coding and General Survey Administration

Well developed questions are the key to easy coding. Surveys that are difficult to code may cost more time and headaches than any other aspect of the effort (particularly if the coding is done by clerks unfamiliar with the issues in the survey). The use of numerical data is one key, as is the use of good database software. Front-end time used to develop a good codebook and set up a coder-friendly database format is almost always well spent.

In regard to general survey administration, developing a systematic process is critical, particularly for larger efforts with several sub-samples. Using different colored paper for different reminder letters or surveys is one simple device for avoiding confusion with mass mailings and returns, but the actual details of the system are unimportant. The important thing is to establish an easily implemented routine for the clerks who will be managing the effort.

A Final Note

Don't conduct a survey yourself unless you have the technical expertise to do a good job. As with any other kind of scientific information, the quality of the data is likely to be directly related to the care, skill, and experience that goes into collecting it. In the case of surveys, you often "get what you pay for."

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have the necessary knowledge about how flows and conditions are related, nor have they thought much about which flows or conditions they prefer. Even with an experienced sample, researchers need to carefully explore the knowledge users may have of different flows or conditions. In some cases, users may only be parroting conventional wisdom about the best flows or conditions without having thought much about their actual experiences with different flows.

Another potential problem with flow comparison surveys concerns having experienced users respond to questions about the best flows or conditions for novice or less experienced users. The novices may not know what they need or prefer because they have not seen the river at many flows or do not focus on the issue. However, the highly skilled experienced users who can answer questions about flow or condition preferences may not be able to make accurate judgments about what less skilled users want. This is a particularly important issue with whitewater rivers, where the flows that experts prefer are often considerably higher than what novices would enjoy. Having noted this potential problem, our experience suggests that many experts can adequately describe the flow needs for non-expert users as long as they are clearly asked to do so. All expert boaters were novice and intermediate boaters in their past; with this issue they are simply asked to remember what those skill levels were like.

A final key to conducting a successful flow comparison survey is the presence of some sort of flow gage for the river in question. All the questions in the survey will relate to some sort of flow or stage measurement, and users have to be knowledgeable about those flows or stages. It is not necessary that this gage be a formal measuring device (e.g., operated by USGS or some similar organization); as long as users have some stage reference on the river (even an informal gage such as a rock or bridge pylon with markings), it is possible to determine which flows they are evaluating at different times.

SUMMARY

As a category of methods for evaluating flows or flow-dependent conditions, survey methods are generally the best. Experienced recreation users typically know about the flows and flow conditions upon which their trips depend; survey methods simply provide the means for researchers to extract that knowledge from them. No other set of methods so directly allows the potential "client" of the river help determine the "product" that will be provided.

Survey-based methods do have their shortcomings in several situations, however. They are generally inappropriate for exploring long-term or indirect effects (which users may not recognize or understand), nor can they be employed for activities where users are largely insensitive to changes in flows or flow-related conditions. In addition, the usefulness of survey data depends in large part on the skill and care with which the surveys are conducted. A poorly conducted survey of less experienced users, for example, may provide less reliable information than a well-conducted professional judgment effort.

Figure 32. Surveys probably provide the most useful way of evaluating flows or conditions. When asked in appropriate formats, recreationsts can usually identify their flow preferences.

The relatively complicated methods for estimating flow needs for fish are often held as a model for recreation researchers to emulate. In fact, however, the converse may be more correct. If fish could talk, biologists would certainly ask them to specify their flow preferences rather than go through the contortions of habitat modeling. With recreation user surveys, researchers actually have the opportunity to learn directly what conditions are minimally acceptable or most preferred. If users on a river know about or have preferences for different flows and/or conditions, researchers should certainly plan to use one or several survey methods to obtain this information.

PREDICTION-BASED MODELING METHODS

Models of the flow-recreation relation have considerable appeal. The basic idea is to use generally available data about the relationship between flow evaluations and changes in flow from one situation and apply it (generally using equations, but sometimes using physical models) to situations where data is not available. A model is particularly useful when a site-specific study of the relation of flow to recreation quality would be too expensive or too time-consuming to conduct, when a reasonable range of flows cannot be observed (e.g., when dam operators are uncooperative), or when the user population is difficult to identify (e.g., on remote Alaskan rivers). At times, the flows to be considered are not observable or measurable, for example, when recreation assessments are being made for a flow-regulating facility that does not yet exist. For such assessments, some model of the effects of instream flow on recreation is essential. The following section presents brief discussions of four important kinds of modeling methods: the single transect method, the incremental method (IFIM), predicting flow needs based on hydrology variables, and physical modeling methods.

SINGLE TRANSECT METHOD

This method refers to the use of cross section or hydraulic geometry information (see discussion in Chapter 4, pages 19-21) to model flows depths or wetted perimeters created by different flows. Most commonly used to explore boatability or boat passage through shallow reaches, the method may also help identify flows that inundate camping beaches or fishing areas.

When applied to boating, the method is best understood by thinking about an imaginary box defining a boatable channel (see Figure 33) and placing it into a cross section of a critical reach (usually a riffle). When this box can "fit" into the cross sectional profile of the riffle at a certain flow (it rests on the river bottom and its top is even with the waterline), a clear channel is said to exist and the flow is considered boatable. When applied to the inundation of camping or fishing areas, the method simply identifies the flows that would cover them.

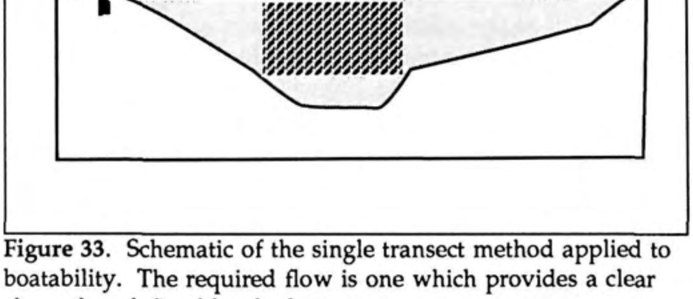

Figure 33. Schematic of the single transect method applied to boatability. The required flow is one which provides a clear channel as defined by the box.

Advantages and Disadvantages

The single transect method is generally quick and easy to apply, requiring only a short field trip to determine critical reaches and conduct the transects. The technique is also appealing because it seems based on relatively simple logic. Compared with many other methods that depend upon complex analysis of subjective data (survey methods) or professional judgements, the single transect method appears more "objective."

Unfortunately, the method is not as straightforward as it first appears and it involves some elements of subjectivity as well. When applied to boatability, one complication is that the method assumes that a clear channel in a critical reach defines acceptable boating. In fact, there are some boating or quasi-boating activities (tubing) where boatability may not defined by a clear channel, and others where a clear channel is necessary but not sufficient. For example, it may be acceptable to an anglers using a canoe for transportation to have to get out of their boat a few times per day to drag it through shallow riffles. Likewise, tubers may not mind occasional shallow riffles. In either case, the single transect method would overestimate needed flows. In contrast, boatability in boulder-strewn, whitewater reaches is rarely dependent upon the existence of a clear channel alone. The more important boatability concern is the location of various obstacles relative to the location of hydraulics and faster water. There may be a clear channel, but the boater also has to be able to use it. In this case, the method underestimates flows.

Another complication comes in choosing the critical reach where flows will be modeled. If the river has only one shallow section and you are interested in boatability, this is hardly a problem. However, on many rivers boatability is an issue through several areas, each with different channel profiles, and each requiring different flows to provide the clear channel (or fit the "box"). Which should be used?

Finally, and perhaps most importantly, the method requires judgements about the dimensions of the box, which depends upon the type of craft, the way it is loaded, and the skill of the boater. Similarly, when applied to the inundation of camping or fishing areas, the most important judgement comes when deciding how much of the beach must remain uncovered for it to be usable. How these or similar judgements get made are at the heart of the method, and all remain arbitrary to some degree. In many cases, the work involved in developing defensible dimensions of the box provides enough direct information about boatability so as to make the method unnecessary.

Keys to Success

The most critical issue with this method is choosing the dimensions of a boatable channel or defining when a camping or fishing beach is too flooded to use. Users and actual field testing should be involved in the development of either criteria for the river in question. With regard to downstream boating, we have generally found that four to eight inches invariably defines boatable depths for open canoes, kayaks, and smaller rafts, but it is more difficult to decide upon appropriate widths. On lower gradient rivers (less than 10 feet per mile), where boaters would have little trouble lining up a channel through riffles, widths should be slightly larger than the width of the craft in question. On faster moving rivers, however,

Figure 34. The single transect method can be used to identify minimum flows for boatability, but it offers no information about other recreation attributes such as whitewater.

researchers should consider greater widths that allow boaters to pass through at an angle. For example, for a seventeen foot canoe to run a riffle with the boat 45 degrees to the current, a twelve foot channel width is required. Similar allowances can be developed for upstream boating (powerboating).

Choosing the transect location is the other crucial issue. Ideally, the transect should be the most shallow reach of the river. However, in many low gradient rivers it is hard to tell which riffle is the most shallow (and these often change from year to year). In such a case, a "representative" riffle is used. The ability of the researcher to estimate which riffle is representative thus comes into play. At least one trip down the river at a low to medium flow is necessary to make a good choice of the appropriate transect location. The other option is to make a single trip down the river and conduct transects at several riffles and choose the most shallow one back at the office.

The technical side of the method can also be important; choosing the specific site for a transect, conducting it well, and modeling flows back at the office requires some expertise and the appropriate computer software. A qualified hydrologist should supervise this work.

Summary

This method can be useful for evaluating flows with the two cases mentioned (boatability through shallow riffles and the size of beaches or point bars due to flooding). However, the method provides little information about flows for other attributes and for many other types of river recreation. The method also involves some arbitrary judgements and requires careful on-site work. The efficiency and focus of this method are advantages, but its limits are sharp. This method is best used in tandem with other methods exploring a wider range of flow-dependent attributes.

INCREMENTAL METHODS (IFIM)

Hyra's (1978) "incremental method" is an adaptation of the U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology procedure for fish habitat modeling. It has been applied in a limited number of cases since (see case study sidebar for James River in Virginia, pages 51 - 53). The incremental method has three basic elements:

- Evaluation of the "probability of use" or "suitability" of various combinations of depth and velocity for a specific recreation activity. This evaluation is generally based on professional judgement or some limited discussion with users.

- Computer simulation of the depths and velocities that exist on a stream reach at different flow levels based on transect data.

- Computer-based calculation of "weighted usable surface area" or the amount of "recreation habitat" (area with acceptable combinations of depths and velocities as determined from the suitability curves) at different flow levels.

The "weighted usable area" calculation for each flow is the output from the model, and can be plotted on a graph against flow. The resulting incremental curve essentially describes how changes in flow produce different amounts of river area suitable for the recreation activity and river segment in question.

Advantages and Disadvantages

The IFIM-based model is notable for its attempt to account for the spatial element of the recreation environment. The model is also useful because its output is both quantitative and incremental and thus can be inserted into a flow negotiation process. In addition, the model allows researchers to simulate physical conditions over a range of flows (including those they may not otherwise be able to observe or measure). Unfortunately, the model also has a number of shortcomings.

First, the model assumes that depth and velocity are the two most important streamflow characteristics for determining recreation quality when other variables may also be as important. For example, while depth and velocity may be the most obvious variables for looking at wading or navigation through a shoal area, more complex variables are needed to understand attributes associated with whitewater or aesthetics. In addition, experienced river users are more accustomed to thinking of recreation quality in relation to flows, expressed in cubic feet per second or stage readings from a gage, so translating into depths and velocities may be unnecessary and confusing.

Second, the model assumes it is possible to determine minimum, maximum, and optimum depth and velocity combinations for recreation activities, without providing much guidance as to how this should or could be done. In most cases, the researcher supplies the evaluative judgments (the suitability curves) for different activities and translates those judgments into velocity and depth requirements. Lacking a survey of knowledgeable users, however, these evaluations may have shortcomings, all of which are then transferred to the subsequent model (see discussion above on professional judgement methods).

Third, the model equates optimum recreation "potential" with maximum weighted usable area (the flow that creates the greatest surface area with good depth and velocity combinations). But having more area of a certain depth and velocity does not necessarily mean recreation quality is maximized; in many cases users don't care if there is a large area with certain desirable characteristics as long as there is **some** area with those characteristics. For example, a boater going through a shoal area does not need a channel hundreds of feet wide – just a channel. Similarly, a larger pool area for swimming is not necessarily better if users still only swim close to shore. The weighted usable area variable also seems a forced and unnecessarily complex way to express recreation quality in relation to flows.

Fourth, hydraulic modeling of flow based on selected transects will often inadequately describe the complex nature of water movement in rapids. The effects of rocky, uneven surface formations at various flow levels on boating quality can probably be more directly and accurately assessed by simply running the river at selected flow levels (or by interviewing people who have experience doing so) and then discussing their characteristics in descriptive ways.

Finally, suitability curves must be calibrated for each specific river reach and should not be generalized to different reaches, where primary recreation demands may be different. Recalibration thus becomes a problem when resource managers want to apply recreation curves, developed elsewhere, to their own rivers. The same problem occurs when suitability curves for different fish species are applied to dissimilar habitats.

Keys to Success

Successfully applying the IFIM framework to recreation issues depends on a number of factors, some of which are further discussed in the sidebar on the James River effort. Issues of particular concern include "habitat" mapping, transect placement, the development of suitability criteria, and the display and interpretation of model output.

There is considerable flexibility in the design and application of an IFIM study. Effective use of IFIM as a tool for evaluating and quantifying recreation values requires a good working knowledge of the IFIM process, the concepts of habitat modeling, and the flow-dependent factors that affect recreation.

Summary

Is the IFIM framework the best one for addressing flow-based recreation issues? In most cases, probably not. IFIM is conceptually attractive: the approach is based on commonly accepted theories of habitat evaluation used for fish, it is rigorous and scientific, and it produces quantitative output. However, in practice IFIM is a complex process with limited application. The advantage of using this framework -- that it is also used to assess fish habitat, thus offering comparability with aquatic habitat assessment -- is generally outweighed by the time-consuming transects required to obtain depth and velocity measurements and by the relatively complex weighted usable surface area computations.

In addition, depth and velocity are not the most direct ways to depict the physical environment, at least for activities such as whitewater boating and aesthetic viewing where flow itself can be more easily assessed. Weighted surface area also lacks a demonstrated relation to the dependent variable, recreation quality.

Finally, an on-site, experience-based assessment of recreation quality is generally needed to calibrate the suitability curves with this approach. Once this is done, the essential recreation quality information has been obtained, and it can generally be more easily obtained in terms of flow or stage than depth and velocity. Fish biologists developed a model as complicated as IFIM because they are unable to talk to fish and find out directly which flows are best. With recreation, it is possible (through survey methods) to find out user preferences without this kind of modeling, and in general this seems to be the more reasonable approach.

In spite of these criticisms, information produced through IFIM modeling efforts may have some usefulness in certain situations. The ability to model a river's hydraulics at different flows is a useful tool for exploring certain flow-condition relationships such as boating navigation, and IFIM extends and improves upon the logic of the single transect method in that regard. In addition, examining depth and velocity constraints for some activities such as wading or swimming (not coincidentally, these are the human activities which are most parallel to fish activities) may offer an interesting approach. Finally, because many recreation studies are co-conducted with fishery studies, use of IFIM may offer opportunities for good interaction between scientists.

Applying IFIM on Virginia's James River

The Falls of the James is one of Richmond, Virginia's premier recreational resources, providing outstanding opportunities for swimming, tubing, boating, and whitewater rafting and kayaking. When a municipal water diversion project was proposed upstream of the Falls, federal and state regulatory agencies initiated a study of impacts on fish and recreation resources. Recreation researchers utilized an IFIM approach (in conjunction with fish studies) in addition to conducting on-site surveys and exploring historical use data to evaluate flow needs for various activities. The use of IFIM for recreation is discussed below, based on experience from that study.

"Habitat" mapping

Different physical stream characteristics (pools, runs, riffles, etc.) tend to attract and support different recreation activities. Low gradient pools, for example, typically provide good opportunities for swimming, while high gradient areas with ledges and rock outcrops tend to provide good conditions for whitewater.

Flows have different effects in different recreation "habitats." For example, changes in flow may have relatively small effects on depths in pools for swimming, but relatively large effects on depths in riffle areas for boating or turbulence for whitewater. The evaluation of flows for a particular activity should focus on those areas (habitat types) that support that activity. The first step in using IFIM for recreation is to map these different habitats and understand how each is used.

Transect Placement

The second major issue in adapting the model is selecting appropriate transects. Transects should be established in locations that are either representative of a particular habitat type or reach, or are otherwise important or sensitive for recreation. Representative transects allow the model to simulate conditions over a large area while critical transects are used to investigate more site-specific issues such as boat passage. If transects are not specifically selected to represent important recreation features, then IFIM results may not accurately characterize recreational opportunities.

Suitability Criteria

The development of suitability criteria is the third major issue and perhaps the most important. It is here that the researcher (sometimes with the help of users) makes decisions about the preferred depths and velocities for a given recreation activity. Figures 37 and 38 (page 54) provide examples of suitability criteria developed for floating on the James.

Developing defensible suitability criteria is a key component in applying IFIM to recreation. For fish, suitability criteria are generally site-specific and based on actual observations of fish behavior. With recreation, the criteria came from professional judgements and a limited body of literature. Although some site-specific studies have been done, there is a need for more empirically-based suitability judgements, including a need to explore other variables beyond depth and velocity.

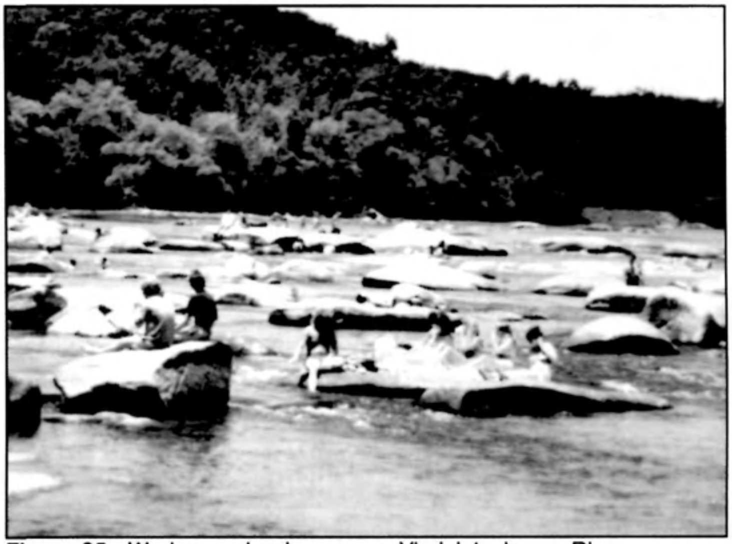

Figure 35. Waders and swimmers on Virginia's James River. Researchers applied the IFIM approach to determine flow needs for a variety of activities.

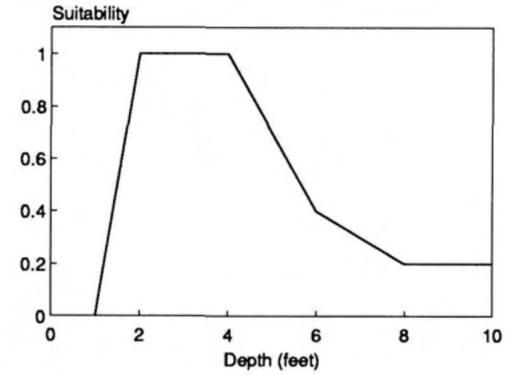

Figure 36. Depth suitability criteria for boating. Minimum depth is 1 foot and optimum is 2-4 feet, although depths from 6-10 feet are acceptable.

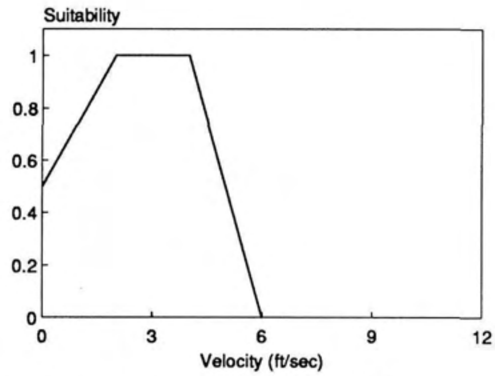

Figure 37. Velocity suitability criteria for boating. Velocities of 1 to 3 feet per second are most suitable, while those over 6 feet per second are unsuitable.

Model Output

The final issue in applying IFIM to recreation is developing meaningful model outputs. One effective way to display results is to show cell specific suitabilities for selected transects as shown in Figure 38. These allow researchers to directly view suitable areas, note where they are located in the river channel (with respect to the shore), and see how suitability changes with changing flow.

Using an index of suitable habitat area (called Weighted Usable Area or WUA), overall suitability can be calculated on a transect-specific basis or for an entire reach or habitat type. By plotting WUA against flow, it is possible to explore how overall usability of the stream reach is related to flow. Figure 39 shows the relationship between flow and WUA for three James River activities.

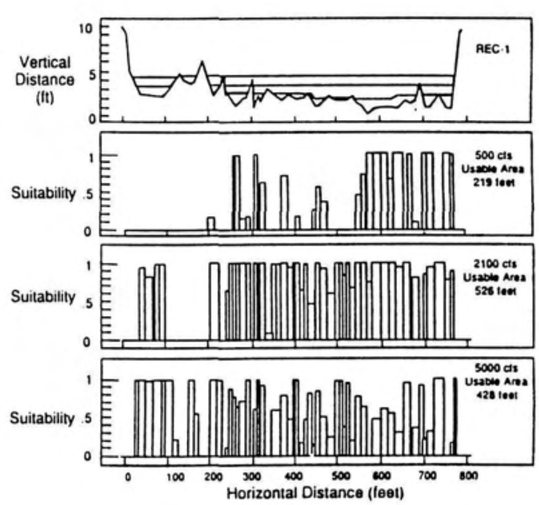

Figure 38. Cell specific suitabilities for wading at a low gradient shoal transect at three flow levels.

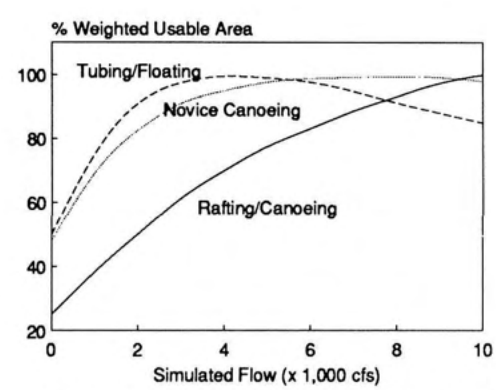

Figure 39. Relationship between flow and weighted usable area for three different recreation activities.

Applying IFIM on Virginia's James River (Continued)

WUA as a Measure of Recreation Potential

A fundamental assumption of the IFIM approach is that weighted usable area is an accurate measure of recreation potential. Conceptually this may seem reasonable, although one can imagine cases where the total amount of usable space is irrelevant. In these cases, what matters is not the total area that provides good conditions, but the quality of habitat in a specific critical area such as a boating chute or fishing hole.

This issue was tested on the James for canoeing as shown in Figure 40, where WUA - flow plots from the IFIM analysis have been overlaid on user preferences for various flows (from survey data). In this case, it appears there is strong agreement between WUA and user preferences. However, when similar data were explored for whitewater boating, the agreement was much less strong because whitewater requires specific rapids with particular characteristics, and WUA is not a good measure of quality. Because it is impossible to know a priori whether WUA will correlate well with recreation quality, it is necessary to conduct survey work to check the model's usefulness. Before one can rely on the model alone, research would need to establish when and under what conditions a close relationship can be expected between model output and actual user evaluations.

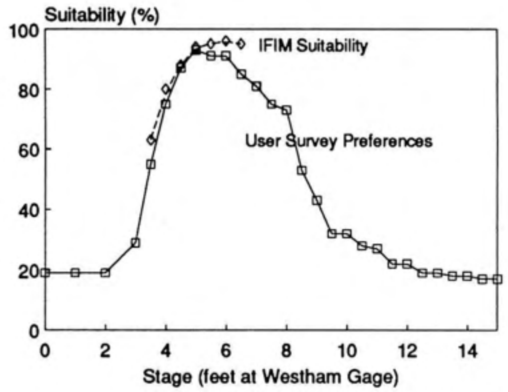

Figure 40. Comparison of suitability curve for boating generated from the IFIM modeling effort with user preference curves from a survey.

This sidebar was contributed by Bruce DiGennaro of EA Engineering, Science, and Technology

PREDICTING RECREATION FLOW NEEDS FROM HYDROLOGY VARIABLES

The idea that recreation flow needs may be reliably related to some hydrology variable such as mean annual flow suggests another type of modeling method. The pioneer effort in this area is the Tennant Method (see sidebar on page 55), but the most recent and significant work in this area comes from Corbett (1990), who developed a statistical relation of minimum boating flows to mean annual flows.

Using data from 45 rivers in the east and mid-west, Corbett focused on estimating "canoeing zero," the flow where an open canoe "touches gravel bars lightly in shallow areas two or three times without slowing down," assuming the person paddling is a skilled technical paddler "accomplished in reading water on very shallow streams." Canoeing zero flow was estimated from the personal experience of the author and his acquaintances, selected interviews, and references to selected canoeing guide books. Corbett also collected U.S. Geological Survey data on mean annual flow for each river. Regression of canoeing zero flow on mean annual flow resulted in a formula that appears in a graphic presentation to accurately specify the relation between these two variables (statistical measures of association were not reported).

Recreation professionals working for the State of South Carolina have developed similar relationships on Piedmont streams between minimum navigation flows for small powerboats and mean annual flow. The variance explained (R^2) for this relationship is surprisingly high at 0.93. For more information on this effort, see DeKozlowski, 1988.

Figure 41. Corbett has developed a model for predicting "canoe zero" from mean annual flow, but the model has sharp limitations.

Advantages and Disadvantages

Modeling methods such as these avoid the complication of depth and velocity criteria used in the IFIM framework by expressing the judgments directly in relation to flow. By incorporating data for 45 river sections and statistically relating the recreation variable to flows, the Corbett method also moves toward greater generalizability. However, there are a number of shortcomings with this approach (Shelby and Jackson 1991), which essentially only provides "rule-of-thumb" information.

First, average annual flow may by itself be insufficient to adequately represent the boating environment of all but carefully selected hydrologically and morphologically similar rivers. Corbett has acknowledged the potential importance of additional variables such as bottom roughness and geologic composition and in later iterations of his report he has developed models for two different kinds of rivers -- those with flatwater (Class I or less) and those with whitewater. Other potentially important hydrologic characteristics include meanders, constrictions such as canyons, and presence of boulders of different size. Without such refinement in stratifying rivers, there may be considerable prediction error. For example, Corbett showed New England streams where the model formula predicts canoeing zero at 150 cfs, while his own on-site assessments put canoeing zero in a range from 100 to 300 cfs.

Second, the model is initially based on professional judgments about what constitutes a canoeing zero flow – the number of hits that are considered acceptable, the type of canoe and how it is loaded, and the skill of the paddler. Without denigrating the Corbett data set, which is without parallel in its breadth and consistency (Corbett personally ran most of his rivers at near-marginal levels over a dozen times before he felt comfortable with his estimates), the estimates are still largely based on his judgments and should be verified by others.

Finally, it should be remembered that canoeing zero is not the only important boatability criterion. For example, data from the Dolores River in Colorado (Shelby and Whittaker, 1990) showed that minimum boatable flows are different for open canoes than for rafts, and that minimum boatable flows are considerably less than the flows needed for minimum or optimal whitewater. In addition, canoeing zero is obviously unrelated to other kinds of non-boating river recreation and it does not begin to address indirect effects of flow regimes on river conditions such as beaches or vegetation that may be important for recreation.

Keys to Success

At this time, these types of models require considerable improvement for widespread use. The current Corbett models (one for flatwater, one for Class III and less whitewater) only provide information about the canoeing zero level and are based upon professional judgment techniques. The South Carolina model relating mean annual flow to minimum navigation flows also only explores a single criterion for one type of recreation (powerboating) on one type of stream (Piedmont rivers), even though its estimates are based on a more replicable technique (single-transect methods in critical shoal areas). These efforts need to be expanded.

The key to this expansion lies in designing site-specific studies that systematically collect comparable data. It is possible to examine relationships across studies only if those studies include the same hydrology and recreation measures. Although Corbett's data set contains comparable measures for 45 rivers, the focus on single-value minimum flows (canoeing zero) and averaging across time (annual average flow) limit its usefulness. There is tremendous potential in such broad data sets, however, if comparable parameters are measured and if the information is made available through publications. A critical need in this regard is some agreement on the variables that should be routinely measured and reported during the course of an instream flow assessment. Appendix A lists these variables.

Summary

Corbett's conclusion that "the river planner can develop a defensible statement of the minimum instream flow for recreational boating when average annual flow is known" oversimplifies the issue. But his modeling effort, the first attempt at an empirical boating recreation model based on data from multiple rivers, demonstrates an important direction for future work. Modeling efforts hold promise as a means of transferring understanding of the relations between recreation and instream flow from one situation to another. Such models will be essential for characterizing recreational suitabilities for flows that do not currently exist or that cannot be easily observed.

Despite the potential of generalized statistical models, however, carefully designed site-specific studies are still necessary for the foreseeable future. The Corbett and South Carolina efforts suggest there may be some fairly predictable relationships between flow needs for certain specific activities and various hydrologic variables, but the relationships are likely to vary for different kinds of streams. More empirical evidence must be amassed before one can say whether these relationships will hold. In the meantime, the "answer" provided from a Corbett-like model should be regarded as an office-based approximation or starting point for exploring recreation flows rather than a final estimate of flow needs. The models provide useful estimates for planning more in-depth work, but they are not an acceptable substitute for that work.

Recreation and the Tennant Method

The "Tennant" or "Montana Method," developed by Don Tennant of the U.S. Fish and Wildlife Service in the 1960's and 70's, was a pioneering technique for assessing instream flow needs for aquatic resources. Based largely on professional judgment, the method provides a "rule of thumb" index of instream flow needs as percentage of average annual flow. The method suggests that instantaneous flows equal to 10 percent of mean annual flow provides only short-term survival habitat for most aquatic species, while 30 percent is needed as a base flow for "good" habitat; and 60 percent is needed as a base flow for "excellent to outstanding" habitat.

Tennant developed the method while traveling the west as a fisheries biologist. Every time he crossed a river or stream he stopped and rated the quality of aquatic habitat (at that flow) based on his professional judgement. He also took a photograph of the site. Later he would call USGS to determine the flow on that day and the river's average annual flow, writing the information on the back of the photograph. He then divided the observed flow by mean annual flow, thus expressing observed flow in terms of percentage of mean annual flow. Over time, Tennant sorted the growing number of photographs by ratings and developed the categories defined by the 10, 30, and 60 percent rules. Subsequent work by Tennant and many others (often involving more in-depth studies to support the professional judgements) suggests that these or similar categorizations have a great deal of validity when larger-scale studies cannot be completed.

Although the method focuses on aquatic habitat, Tennant has claimed that the 30 and 60 percent rules are similarly relevant for many recreation uses as well. This kind of statement, also based upon professional judgement, is obviously an oversimplification, although the idea may have some validity. Depending upon the type of recreation, there may be a reliable relationship between flow needs and average annual flow. Work by Corbett and the South Carolina resource managers are essentially extensions of this idea, and although each of those models have significant limitations, they suggest that greatly expanded data sets exploring similar relationships across a variety of recreation activities and experiences may have considerable merit. Similarly, while the Tennant Method is still in use as a good first cut estimate of flow needs for aquatic resources, most researchers recognize that greater specificity and more in-depth work is necessary to make definitive statements about a river's flow needs in most situations (Lamb, 1989).

PHYSICAL MODELING METHODS

Physical models involve constructing a scaled version of the river in a laboratory setting. They allow researchers to send varying amounts of water (flows) through the model and measure the different effects (size of waves or holes, amount of sediment transported, erosion, and so forth).

Physical models have been developed for a number of rivers, although in general these models have only been applied to short reaches. The most common application of this method is the creation of "artificial rivers" (human-built whitewater slalom courses) or boating chutes through low-head dams or weirs in natural rivers.

Advantages and Disadvantages

The chief advantage of a physical model is that it is highly quantitative and replicable. Scientists and engineers develop the model to closely approximate the physical features of the river, and can then run different flows down the river and directly measure various effects. Once the model is made, any number of flows can be examined with relative ease.

Unfortunately, this type of model also has at least three significant disadvantages. First, developing an accurate and useful physical model for any significant length of river is extremely expensive. Many scale models seem to be developed near the 1:20 scale, meaning even a one mile long segment of river would require a building about the length of two football fields. In addition, developing an accurate model of a natural river depends on a good survey of the river channel, including the location, shape, and size of boulders or other obstacles. Conducting multiple channel transects along a stretch of river longer than several hundred yards seems impractical.

Second, these models may not depict reality very well in certain situations. Everything in the model is scaled down except the water, which has the same physical properties (density, surface tension, etc.); this can lead to slightly different relationships among the measured variables. Models exploring erosion and deposition, for example, must account for differences in the way the scaled-down model sediments will interact with the unscaled-down water.

Finally, physical models may neglect an important variable: the recreation user. Physical models help scientists measure conditions at various flow levels, but they offer little guidance on how to evaluate those conditions. If the model is being used to explore whitewater boating conditions, for example, scientists can only measure the sizes of waves or the forces and velocities in reversals at different flows. Without a 1:20 scale kayaker to put in the model, it is difficult to tell which waves or holes are best.

Summary

Effective physical models have only been applied to artificial rivers and short reaches of natural rivers, usually when intensive human-built features are contemplated. In almost every case, the model was used less for determining instream flow needs than determining how to modify or build river features that would be safe and provide high quality recreation through the range of given flows. The method is probably only useful for short segments where intensive use is expected, as with whitewater slalom courses or safe boating chutes over low head dams.

Figure 42. An "artificial river" near Nottingham, England which was first developed though physical modeling.

Flows and Artificial Rivers

Artificial rivers built for kayak and canoe slalom courses provide interesting opportunities to learn about relationships between flows and whitewater quality. Designed to provide optimum training and racing conditions for technical paddlers, these courses provide the best setting for controlling and experimenting with the interaction of flows and obstacles to create good whitewater.

The first artificial river was built near Augsberg, Germany for the 1972 Olympics, but a half-dozen or more have been constructed since, including the recently completed courses in Barcelona for the 1992 Olympics and a U.S. training course in Maryland. A list of several prominent courses is given in the table below, along with some of their specifications. Comparing the flows, widths, and gradients among these courses, which are all designed to provide Class II, III and IV technical whitewater over a short distance, suggests several issues for instream flow research.

Course	Length	Avg Width	Gradient	Max Vel.	Flow
Augsberg, Germany	1,600 ft	25 ft	36 ft/mile	18 ft/sec	495 cfs
Vichy, France	1,300 ft	16 ft	46 ft/mile	8 ft/sec	177 cfs
Nottingham, England	2,300 ft	49 ft	27 ft/mile	14 ft/sec	988 cfs
Prague, Czechoslovakia	1,300 ft	32 ft	46 ft/mile	15 ft/sec	600 cfs
South Bend, Indiana	2,300 ft	66 ft	27 ft/mile	13 ft/sec	988 cfs
Bethesda, Maryland	900 ft	60 ft	110 ft/mile		450-650 cfs

First, there is a fairly wide range of flows that can provide quality whitewater, starting as low as 177 cfs and continuing to flows as high as 1,000 cfs. The interesting figure here is the low end, where about 200 cfs is the minimum. On natural rivers, this figure also seems reasonable: informal discussions with experienced paddlers suggest there are few natural rivers that provide good whitewater at flows less than 200 cfs.

Second, there appear to be some patterns to the relationships between width, gradient, and flow. If the channel has lower gradient, more water or narrower widths are required to create a good course. On the other hand, more gradient allows the use of less water, a wider channel, or both. The consistency among these relationships is theoretically understood with regard to rivers in general (Leopold and Maddock, 1953), but no one has examined them empirically with respect to the quality of whitewater. If similar measurements from a sample of natural rivers with roughly equal whitewater quality could be made, it might be possible to develop useful multiple regression models relating those variables to whitewater quality. This is a good area for future research.

Artificial rivers also prove instructive with respect to their origins and cost. In most cases, these courses were extremely expensive to design and build, as well as requiring space in which to build them, and the existence of divertable water for the channel. With the exception of the Bethesda, Maryland course, which was built in an existing water discharge canal from an electric generating station, courses have cost millions of dollars and required advocacy groups to complete them. By contrast, providing necessary instream flows on existing rivers or by-pass channels might cost far less, while offering similar whitewater opportunities and more natural settings for the activity.

CHOOSING EVALUATION METHODS

Preceding sections of this chapter have discussed in relatively close detail the variety of methods that could be used to evaluate flows or conditions. In this summary section, we present two "evaluation tools" designed to help readers quickly understand which method or combina-tion of methods tend to work best for a given river situation.

A Categorization of Methods

The first evaluation tool is a categorization of methods by the degree of sophistication and defensibility they provide (see Table 4). In the first category we have listed methods that are generally quick and easy to implement but provide only "rule of thumb" assessments. These may provide useful preliminary estimates of recreational flow needs, but they lack the ability to provide much depth in understanding how flow is related to recreation quality. If the stakes are high or if there is stiff competition for flows, these methods are unlikely to be sufficiently rigorous during flow negotiations. The second category lists methods with greater rigor and sophistication, but which still fall short of providing the most in-depth understanding of the flow-quality relationship. The final category, in contrast, lists methods which are relatively sophisticated and provide the most defensible information, but which also require more substantial investments of time, money, and expertise.

Table 4. Categorization of various methods by their degree of sophistication and defensibility. In general, lower category methods are easier to apply and less expensive, but they provide more limited understanding of the relationship between flow and recreation quality.

Category 1	Category 2	Category 3
Historical use method	Single visit professional judgement	Multiple visit prof. judgement
Tennant method	Interviews with experienced users	Single flow surveys
Corbett method	Focus group meetings	Flow comparison surveys
South Carolina method		Controlled flow assessments
		Surveys using slides/video
		IFIM-type predictive modeling
		Physical modeling

A Decision Tree for Choosing Among Methods

The second evaluation tool is a decision-tree that suggests the method options when different kinds of information are available (see Figure 43). Depending on the kind of river and recreation use, certain methods tend to work better than others. Readers should note that the decision-tree provides a highly abbreviated version of the most important factors in choosing among evaluation methods, and that many other factors may go into a researcher's choice of one technique over another.

Neither of these "devices" is intended as a mechanical substitute for a considered choice of methods. As this chapter should have made clear, there are a variety of ways to collect and process evaluative information about flows and recreation, and no one method provides the only answer. With the best studies, researchers generally utilize some combination of methods to explore the issue from several different angles.

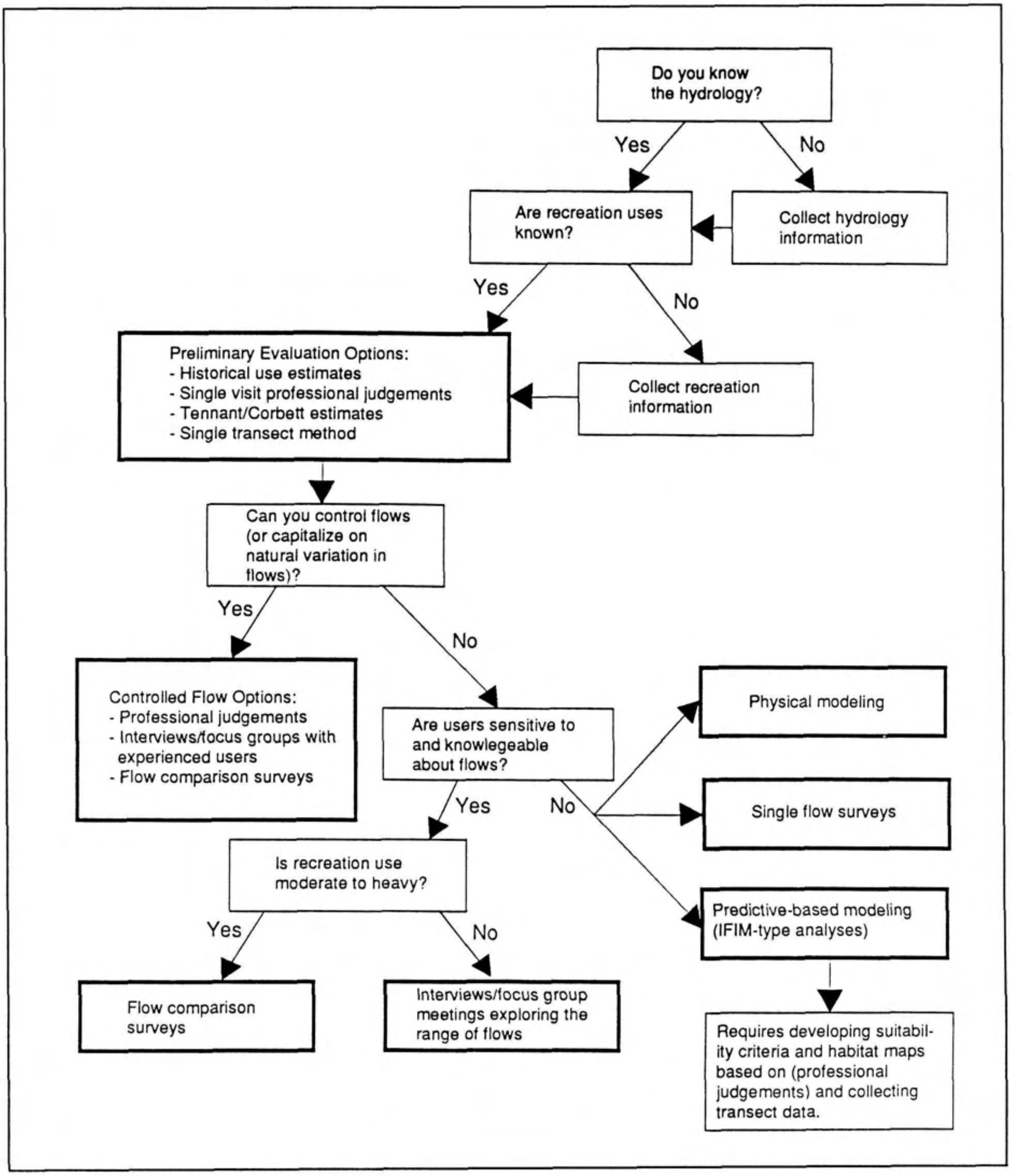

Figure 43. Decision-tree for choosing among evaluation methods based on the availability of various kinds of information. Readers should note that this schematic is a highly abbreviated guide to choosing methods. Most studies will use a combination of methods, and most methods can be adapted to various situations.

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Notes:

Chapter 6
EXAMPLES OF FLOW - ATTRIBUTE RELATIONSHIPS

This chapter focuses on the direct effects of flow on recreation resources, presenting a series of examples of flow - attribute relationships. The idea is to suggest the kinds of output most studies produce. For each relationship, we present an actual or hypothesized relationship and the keys to developing it. The most suitable methods for developing the relationship will also be discussed. The majority of these flow - attribute relationships focus on direct effects of flow on specific **flow-dependent activities** such as boating, swimming, or fishing. Recreation quality for these activities is intimately tied to flow conditions, so they generally receive the greatest attention during most instream flow studies (and in this handbook). However, a number of attributes (particularly those indirectly affected by flow) are crucial to the quality of **flow-enhanced activities** such as wildlife viewing, hiking, or riverside camping and they should be explored as well. Some of these issues were covered in more detail in Chapter 4. In this chapter, the final section on aesthetics also briefly discusses how changes in flows may alter attributes connected with flow-enhanced activities.

BOATABILITY

Boatability, as discussed here, refers to the low flow issue of getting boats up or down a river without hitting obstacles in the channel. It is one of the most obvious examples of an attribute directly affected by flow: decreases in flows generally mean boats are more likely to scrape bottom, get hung up on rocks or gravel bars (becoming "stopped"), or require boaters to get out of their boat and drag it across shallow reaches. The lack of boatable flows can significantly detract from users' trips.

In most cases, boatability will be related to flows as shown in Figure 44. At low flows problems will be frequent and even large increases in flows will fail to substantially diminish them. At some point, as flows fill and create a clear channel, boatability problems will decrease sharply with only small additions in flow. Eventually, a clear channel will be available and boatability will be uniformly high.

Key Issues

Developing a defensible relationship between flow and boatability requires consideration of the issues listed below.

- Relationships between flows and boatability will differ for different types of craft with different loads, and studies need to explicitly define any assumptions in this regard. In general, the curve hypothesized in Figure 44 will shift to the right for larger or less maneuverable craft, or for those carrying heavier loads.

- Flow-boatability relationships will differ for boaters with different skill levels, and studies need to state any assumptions about this variable. In general, the curve presented in Figure 44 will flatten out for more experienced or skilled boaters (i.e. lower and higher flows are more acceptable).

- Flow-boatability relationships may change on a river as its channel changes, and flow needs should be developed for each segment with different channel characteristics. In general, the curve presented in Figure 44 will shift to the right for less uniform, more boulder-filled channels.

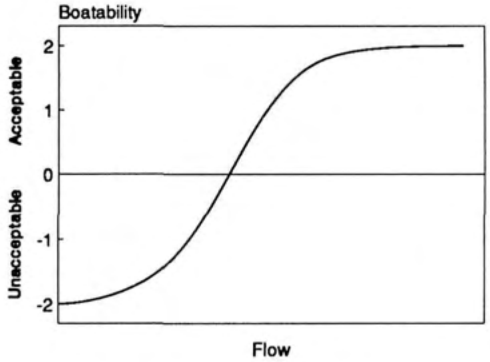

Figure 44. Hypothesized relationship between flow and boatability.

Figure 45. Boat dragging on Alaska's Birch Creek. Boatability is an attribute directly affected by flow.

- Boatability can be defined in a variety of different ways, depending on the type of experience desired. For some trips, any boatability problem -- any obstacle to travel -- may be obtrusive; on others a certain tolerance for problems may exist. Accordingly, studies should systematically define the nature of problems as well as the number of such problems users will tolerate for various types of experiences. The sidebar below and opposite provides an example of how this might be done.

Methods

A combination of professional judgement, transect-based, and survey-based methods are generally the most useful for exploring this relationship. Survey-based methods are the key to developing definitions of obtrusive boatability problems or tolerances for them, but any of the other three methods can provide useful information about the likelihood of those problems at different flows. Transect-based methods are especially useful in this regard, particularly if transects are placed at representative riffles or other areas critical for navigation. In the case of powerboat navigation, where any contact with the channel has the potential to ruin a trip, a single transect at the shallowest place on the river may provide all the information needed to address the boatability issue.

Evaluating Boatability: An Example

Developing a relationship between flows and boatability begins with definitions of boatability problems and users' tolerances for them. The following example, taken from a study on Alaska's Birch Creek National Wild River, presents one approach. Readers should note that this study focused on canoeing and rafting only, although similar definitions and tolerances could easily be developed for other craft.

- **Hits** refer to times when a canoe or raft hits a rock or gravel bar and is slowed or deflected but not stopped. Hits are the least obtrusive boatability problem.

- **Stops** refer to times when a canoe or raft is "hung up" on a rock or gravel bar. A stop differs from a hit in that the boat's forward momentum is lost. In order to get "unstopped," boaters must push off the obstacle with a paddle, an oar, or a foot. Shifting weight in the boat (having a passenger move) may also be required. Stops are also relatively unobtrusive boatability problems, unless they happen frequently.

- **Boat drags** refer to times when boaters have to physically get out of their boat and drag it across a series of boulders or a gravel bar. A boat drag is a more severe boatability problem than a stop, and typically means pulling the boat across several feet of obstacles. Even a few drags per day can be obtrusive.

- **Portages** refer to times when boaters have to drag or carry their boat out of the channel and around some obstacle because of poor floatability conditions. This commonly occurs when there are river-wide sweepers, logjams, or significant rapids at low water conditions. Lining a boat through a rapid is also considered a portage

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Evaluating Boatability: An Example (Continued)

for the purposes of this discussion. Any portage is a major event on a Birch Creek trip (at least below Harrington Fork), because most users do not expect them.

Table 5 presents a matrix showing the number of boatability problems users will tolerate **per day** for five levels of "boatability quality." The five point rating scale is consistent with other research (where surveyed users rated boatability conditions). For Birch Creek, where the user population was too small for a survey, discussions with expert users and field work were the primary sources. Numbers in the matrix should be considered "ball park" figures rather than specific tolerances. The qualitative "experience types" are described below:

- **Optimum** floatability is when there are no problems due to flow levels. In a survey, optimum flows would be defined by an extremely high percentage of users rating floatability conditions as acceptable.

- **Near Optimum** floatability is when there are only minor problems due to low flows. During an average day, a boater may contact with a rock or gravel bar, but these will be infrequent. In a survey, near optimum conditions would be defined by a majority of users rating floatability conditions as acceptable.

- **Marginal** floatability is when problems due to low flows become apparent. During an average day, boaters may make frequent contact with rocks or gravel bars, become hung up on rocks several times, and may also have to drag boats across shallow reaches a couple of times. In a survey, marginal conditions would be defined by about equal numbers rating floatability conditions both acceptable and unacceptable.

- **Boat dragging** refers to conditions when floatability problems are frequent and obtrusive. The type of experience is changed from boating to something else. On a typical day at this water level, boaters will hit bottom more than they can easily count or recall, and they will be frequently "hung up" and need to get out of their boat to pull it across shallow reaches. Portaging around sweepers, log jams, or rapids that are unrunnable due to low water may also be required. In a survey, boat dragging would be defined by a majority of users rating conditions as unacceptable. Most Birch Creek boaters would probably not take a trip at these flow levels if they knew ahead of time what the floatability conditions were likely to be.

- **Unboatable** refers to conditions when floatability problems are almost continuous. At these flows, boats are in constant contact with rocks and gravel bars. Almost every riffle requires boat dragging, and some rapids are unrunnable. In a survey, unboatable conditions would be defined by a vast majority of users rating conditions as unacceptable. While it may be physically possible to get a boat and gear down Birch Creek at these flow levels, trips taken under these conditions are more like stunts than recreation experiences.

Table 5. Experience types and tolerances for boatability problems on Birch Creek, Alaska. Numbers in table are tolerances per day. Explicitly stating tolerances is a critical step toward evaluating flows for navigation.

Experience Type	Rating	Hits	Stops	Boat Drags	Portages
Optimum	2	0	0	0	0
Near Optimum	1	3-5	1-2	0	0
Marginal	0	10	3-5	1-2	0
Boat Dragging	-1	30	10	3-5	1-2
Unboatable	-2	constant	30	10	3-5

A number of studies show that quality of whitewater boating is related to flow. For a given type of craft and a user of a particular skill level, the relationship generally follows a bell-shaped curve as shown in Figure 46 (from Colorado's Dolores River). Below a certain level, boatability problems are an issue. In addition, the water does not have enough energy to form hydraulic features such as waves, holes, and eddy lines which provide the essential medium for whitewater boating.

At the high end of the continuum, flow is so great that the river becomes overpowering. Standing waves and holes become so large that they can flip a boat, and the current is so powerful that maneuvering becomes difficult. Eddies become smaller and more difficult to get into, and they may be obstructed by logs, trees, or other debris. Current "surges" are unpredictable, making boating all the more hazardous.

Figure 46 shows curves from the Dolores River. There were major differences in the flow needs for different boat types. Canoeing in open boats required considerably less water than rafting or kayaking, and kayakers showed less tendency to decrease their evaluations of the highest flow levels considered in the study. The study also showed clear differences between scenic boating (that uses the river as a waterway for transportation) and whitewater boating (where rapids and river hydraulics become an important part of the experience). The study also showed a clear difference between minimally acceptable whitewater and optimal or high quality whitewater.

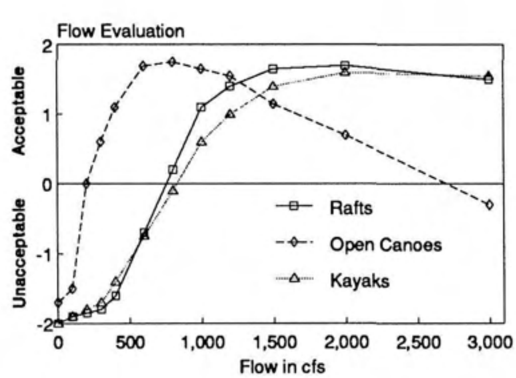

Figure 46. Flow preference curves for open canoers, whitewater rafters, and kayakers on the Dolores River, Colorado.

Key Issues

Flow evaluations for whitewater recreation generally involve professional judgments or user surveys rather than modeling methods. Some of the issues in choosing or applying various methods are discussed below.

- Asking users to evaluate a variety of flows during survey efforts is essential for comparisons to be made. It is also important to survey users who have experience with a variety of flows on the river. Experienced users know the flow levels they run and they think about the effects of flow on the quality of whitewater, difficulty of rapids, safety of rapids, boatability with different types of boats, likelihood of having to portage rapids, etc. The Grand Canyon study (Shelby, Brown, and Baumgartner, 1992) documents a number of these relationships.

- It is very important to stratify information for boaters with different skill levels. Both whitewater challenge and safety are related to the ability of boaters. Highly skilled boaters prefer extremely challenging whitewater and have fewer safety concerns. They often prefer higher flows which tend to provide more powerful hydraulics and require faster moves. Studies simply need to document any differences in preferences between boaters of different abilities.

- Hydrology variables do not appear to adequately represent whitewater characteristics, so modeling methods are not effective tools for exploring them. While some researchers have experimented with Froude number, a measure of turbulence, the connection with whitewater quality has not been demonstrated. In addition, hydrology measurements are difficult to make in places where flow is turbulent, thus eliminating most interesting whitewater. Finally, models rely on some hydrologic characterization to represent an entire river segment. Rivers seldom offer continuous or uniform whitewater because rapids occur at places where there are increases in gradient, constrictions in the channel, boulders in the channel, etc. A whitewater run may have one rapid in a number of miles of otherwise unremarkable flatwater, making it difficult to characterize whitewater quality with any descriptor which represents the entire river segment.

Figure 47. Rafters running into a hole on Oregon's Deschutes River. Many challenging whitewater features depend on particular flow levels.

Methods

Survey methods provide the most appropriate way of evaluating flows for whitewater, although professional judgement methods may also work in situations where a survey is not possible. Among the various survey methods, both single flow surveys and flow comparison surveys may prove useful. Because many whitewater boaters make multiple runs down the rivers in their area and because they are often very knowledgeable about flows (constantly checking with USGS or Weather Service gage reporting services), there may be good opportunities for mailed flow comparison surveys. Because the whitewater reaches on rivers may be short and in the same areas where hydropower dams are located, the controlled flow field assessment is often an option as well.

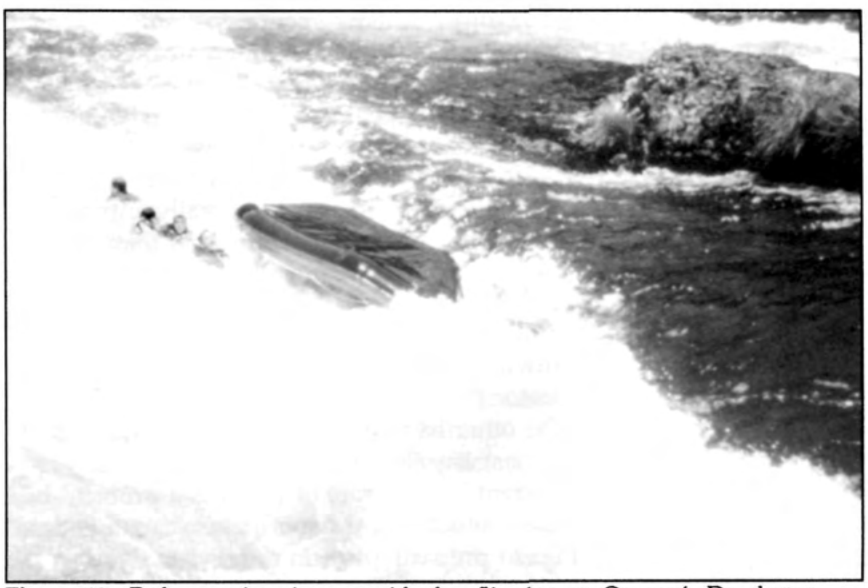

Figure 48. Rafters swimming a rapid after flipping on Oregon's Deschutes. Whitewater safety is also related to flows.

Rate of travel refers to the length of time floaters spend traveling down a segment of river. It is another recreation trip attribute directly related to flow: as water levels drop, currents slacken and it can take floaters longer to travel a particular stretch. The longer travel times can, in turn, decrease the amount of time spent in camps, on hikes, or at lunch, and can also impinge on boaters' schedules.

In general, rate of travel is related to flow as shown in Figure 49. At very low flows, rate of travel will be slower than desirable. As flows increase, rate of travel will also increase to more preferable levels. It is possible that current velocities may continue to increase at higher flows to the point where rate of travel is too fast (the trip ends too quickly), although in most cases this will not be relevant.

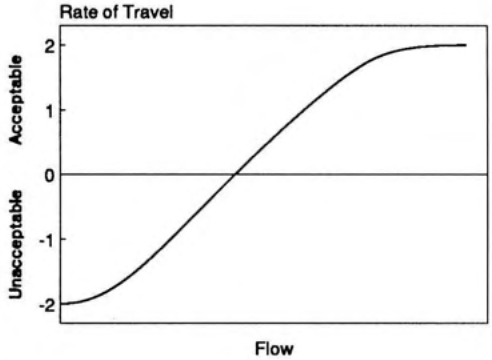

Figure 49. Hypothesized relationship between flow and rate of travel.

Key Issues

Developing a defensible relationship between flow and rate of travel requires consideration of several issues.

- The flow - rate of travel relationship depends on the craft used and the way people take trips. For example, rafts are more sensitive to slow rates of travel than canoes or kayaks (which can more readily be paddled to offset slower current velocities). Similarly, if boaters are willing to increase their rate of travel by paddling/rowing more, or by simply spending more time on the river, slower currents and lower flows may be more acceptable. In either case, the easier it is to counter slower currents, the more the curve shown in Figure 49 would shift to the left (faster rates of travel at lower flows). At higher flows, paddling is unlikely to have significant effects on rate of travel.

- Rate of travel issues are generally a greater issue for longer trips, particularly multi-day trips, when travel schedules may have less flexibility. A ten percent decrease in current velocity has little effect on an afternoon trip; compounded over a five day trip it can seriously detract from a user's experience. or might require and extra day.

- Rate of travel issues are generally a greater issue on medium gradient rivers than either high or low gradient rivers. Low gradient rivers hardly provide any reliable current and the effort users spend paddling or rowing are a more important rate of travel factor than the flow-dependent current. On the other hand, in high gradient situations almost any flow provides a reasonable current. When rate of travel is a problem in these situations, the more likely factor is time spent preparing to run rapids, etc.

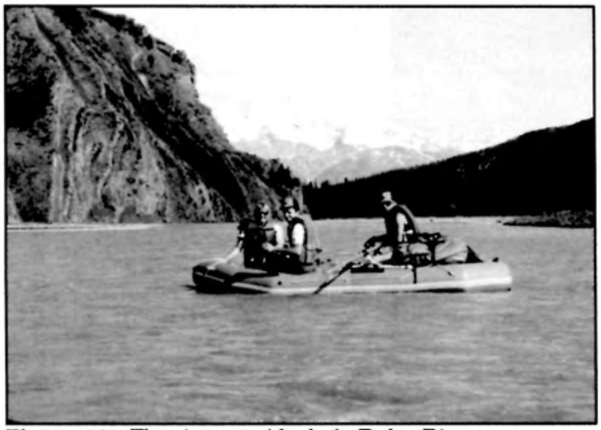

Figure 50. Floating on Alaska's Delta River. Reasonable rates of travel provided by higher flows are often important on multi-day trips.

Methods

Actual flow - rate of travel relationships may be relatively difficult to quantify. Most recreation users do not travel down a river in a uniform manner -- people paddle/row in spurts and make frequent stops or eddy out to look at something; on multi-day trips, they also spend varying amounts of time on the river. However, rate of travel is at least conceptually related to current velocity, which can be associated with various flow levels. Accordingly, rate of travel can be modeled effectively through hydraulic geometry equations or IFIM methods, or measured directly in the field with markers (biodegradable dyes or low saline solutions dumped at a point upstream and then timed through a segment).

In most cases, however, this level of study is not needed and may actually complicate the issue. Rate of travel issues may only be important for a relatively small stretch of a river at certain critically low flows. Professional judgments based on a few trips that involved occasional velocity measurements may thus help expose these problems and suggest when flows approach marginal levels for this attribute. Similarly, survey methods that ask users to specify which flows create rate of travel problems are often sufficient.

FISHABILITY

Providing or maintaining instream flows to sustain healthy fish populations in a river is a prerequisite for providing good fishing opportunities. Instream flow research for fish and fish habitat is focused on this issue, and it will not be covered here. However, there are also flow needs for providing a good fishing experience independent of the amount of water to maintain an abundance of fish. This might be termed "fishability" or "angler habitat" as opposed to fish habitat.

Having a good place to fish from (being able to wade in the stream, backtroll or drift through a hole, or cast from the bank without getting tangled in the vegetation), clear water to fish in (fishing success for many species declines with certain turbidity levels), or good combinations of pools or riffles for catching fish (certain bait, lures, or flies work well in certain situations) all contribute to whether a river provides good fishing, and all may be affected by flow. In addition, flow levels may also affect fish activity levels and thus influence the likelihood of catching a fish. For the purposes of this discussion, fishability refers to the combination of conditions that provide a good fishing opportunity, including all the factors listed above.

Although there are many variations depending on the type of fishing and the target species, fishability will be generally related to flow as shown in Figure 51. At lower flows, many fish populations are likely to be less active and may be more difficult to catch even if it is easy to wade the river and fish are confined to a smaller geographic area. At medium flows, fish activity is likely to increase, as will fishing success. Velocities have not increased dramatically enough to limit wading, trolling, or drifting opportunities, and clarity should still be reasonably good. At higher flows, however, velocity increases so it becomes more difficult to wade, backtroll, or drift-fish in an effective manner and fishing quality declines.

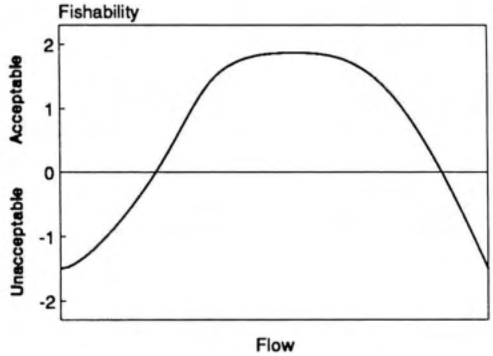

Figure 51. Hypothesized relationship between flow and fishability. This relationship may be different for different fishing techniques or target species.

Figure 52. Wading conditions are related to flow and help create high quality fishing opportunities (from Kenai River, Alaska).

Key Issues

Developing a defensible relationship between flow and fishability requires consideration of several issues.

- Flow - fishability relationships depend on the type of fishing desired, including the kind of fish people are interested in, the kind of bait, lure, or fly they use, and how they fish (in riffles, at holes; wading, trolling, anchoring, or fishing from the bank). Studies need to explicitly identify how people fish before any flow needs can be assessed. In general, the curve presented in Figure 51 would shift to the left for wading anglers and to the right for bank anglers. Generalizations about how the curve might shift for different combinations of boat fishing techniques are more difficult.

- Relationships between flows and fishability may be different for different segments of a river because the channel has changed. In general, for less uniform, more boulder-choked channels, the curve presented in Figure 51 shifts to the right.

- Fishability by itself may be among the most difficult recreation attributes to measure because it actually involves several elements (wadeability, water clarity, fish activity levels, etc.). In addition, there appears to be more subjectivity about some of these elements – in particular, anglers do not always know or agree on the conditions which are best. While elements like wadeability and turbidity can be approached relatively easily, their relationship to fishability is not always clear and may depend on the angler. For this reason, researchers should be particularly careful to involve users in making fishability evaluations, typically through survey-based methods.

Methods

A combination of professional judgement and survey-based methods is critical for exploring this relationship. Survey-based methods may be the only effective way to learn what factors contribute to fishing success and how they might be related to flow. Through these methods it might be possible to determine which water clarity is best, which velocities are unwadable, or what type of riffle or pool conditions are best for anglers. From there, professional judgement techniques may prove most useful, allowing researchers to note which flows create those high quality conditions. In some cases, anglers may be well informed about flow levels when they fish and thus can directly evaluate flows for fishability; in other cases, anglers will know about flows in a more general way, and more specific questions about various aspects of their fishing trip will prove more productive. For this reason, we suspect that on-site survey work (the single flow survey format) is more useful than flow comparison surveys for fishability issues.

Among the elements that create overall fishability, wadeability is one that may be approached through a modeling method such as IFIM. The important issue here is the combination of depth and velocity experienced by anglers, and the IFIM model can provide a measure of usable area for given depth/velocity criteria. However, because anglers tend to need very little wadable area when they fish and seem amenable to moving up or down a river to find a good spot, this method may prove less useful in many situations. Researchers attempting it should certainly employ some field work/professional judgment to verify any findings.

Swimmability refers to the combination of conditions that provide high quality swimming opportunities. Depending on the type of swimming opportunity being provided, there may be issues with the river's depth (enough for diving, wading, etc.), its velocity (low enough to keep swimmers from being swept downstream in most cases, although sometimes floating downstream while swimming is the goal), its appearance (no stagnant pools, etc.), or the availability of associated channel features (sandy beaches or good rocks for sunbathing, sandy bottoms for wading, etc.).

In most cases, swimmability will be related to flows as shown in Figure 53. This curve is essentially the sum of two different curves, one sweeping upward with increasing depth and the other sweeping downward with increasing velocity. At low flows there will not be enough depth for good wading, swimming, or diving. There may also be poor aesthetics and water quality at extremely low flows. As flows increase, pools fill and users have a greater area that provides good swimming, while increased velocities improve the aesthetic sense that the river is alive. Eventually, additional flows no longer significantly affect pool depths and there is more than enough area for users to swim. In addition, velocities at these higher flows will eventually become too swift for less strong swimmers, or sunbathing rocks and beaches may become covered by the water. Other conditions related to flow that may affect swimmability include temperature (in general, higher flows are colder) and channel bottom type (swimmers prefer sand and small diameter gravels, and different flow regimes may maintain or provide these channel bottom characteristics).

Key Issues

Developing a defensible relationship between flow and swimmability requires consideration of the issues listed below.

- Relationships between flows and swimability will differ for different kinds of swimming opportunities. Studies need to explicitly identify the kind of swimming to be provided on the river (wading, diving, "family" swimming, lap swimming, rapid swimming, etc.). In general, diving and lap swimming require greater depths than wading or "family" swimming, and the curve presented in Figure 53 would shift to the right.

- Flow-swimmability relationships will differ for swimmers of different skill levels, so studies need to state assumptions about this variable. In general, less skilled swimmers require slower velocities and lower flows, so the curve presented in Figure 53 will shift to the left.

- Flow-swimmability relationships depend on the type of channel in the swimming area. Flows that may be adequate at one pool may be too low or too high at another. In general, the curve presented in Figure 52 will shift to the right (more flow is needed for good swimmability conditions) in areas where the river is wider, less uniform, or more boulder-filled. Gorge-like channels with steep walls and deep pools are likely to provide good swimming conditions at even extremely low flows.

- Swimming quality may be defined in a variety of different ways, depending on the type of experience swimmers desire. In some cases, swimmers may be intolerant of any swimmability problems (fast velocities,

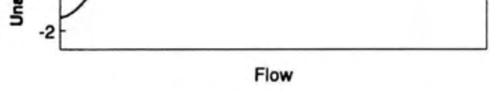

Figure 53. Hypothesized relationship between flows and swimmability evaluations.

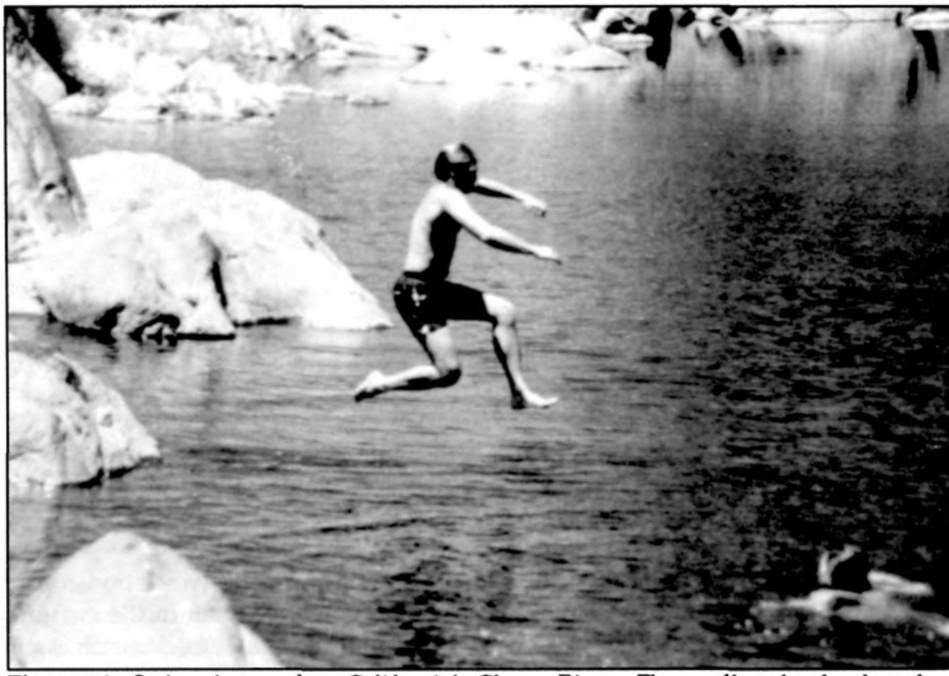

Figure 54. Swimming pool on California's Clavey River. Flows affect the depth and velocity of swimming areas and thus influence the quality of swimming activities such as diving.

stagnant pools, or the lack of a wide area of sufficient depth for swimming or diving), while in other cases those conditions may be acceptable. For example, in the heat of summer, swimmers may tolerate less depth or velocity as long as there is a place to immerse themselves. Studies need to explicitly define swimmers' tolerances. Greater tolerance for low flow conditions would shift the curve in Figure 52 to the left.

Methods

Swimmability is one of the few recreation values that may be effectively examined through modeling methods such as IFIM. In many cases, high quality swimming will be based on two major factors, depth and velocity, the same two factors used by biologists to evaluate the quality of flows for providing fish habitat. For different kinds of swimming, reasonably straightforward curves describing the quality of swimming at various depth and velocity combinations can be developed. Taken together with transect information relating flows to different depths and velocities, it is possible to determine which flows will provide the most high quality swimming "habitat." One problem with this method is that it assumes maximizing swimming area is the goal, when lesser amounts may provide sufficient swimming opportunities. Another problem with this method is that it fails to address other factors (temperature, aesthetics, water quality, availability of sunbathing spots, etc.) that might contribute to high quality swimming experiences.

In these cases, professional judgement and survey-based methods provide the most valuable information. Survey-based methods are most useful for exploring aesthetic issues, but they also can be used to directly evaluate different flows. Professional judgment methods are useful for exploring the channel morphology issues associated with creating preferred channel bottoms or sandy beaches. They may also be used to directly evaluate different flow conditions (a researcher simply visits the swimming area at different flows to assess their swimming potential).

AESTHETICS

Aesthetics refer to the visual or auditory effects of water in a stream. Aesthetics are important both close-up (when users are on or adjacent to the water) and as a scenic component at the landscape level. In addition, they can be directly affected by the instantaneous flows in the river as well as indirectly affected by long term changes in the flow regime. This section focuses on the direct effects; a previous section (see chapter 4) explored some of the indirect effects on channel form and riparian vegetation.

Aesthetics are a particularly important issue for rivers with waterfalls, but aesthetic quality is one attribute that affects all types of river recreation, including flow-dependent activities (such as boating, fishing, or swimming) and flow-enhanced activities (such as hiking, birdwatching, camping, or sightseeing).

At the low flow end of the continuum, it seems clear that visitors prefer some visible water to a dry streambed. Negative effects of low flows include stagnant pools, decreased water quality, stranded features, exposure of algae and possibly trash, and loss of vitality that comes from the contrast between pools and moving water. Higher flows producing visibly moving water (rather than stagnant pools) with accompanying sounds appear to be the most preferred situation.

At the high flow end of the continuum, negative effects of flood flows include drowning of features, loss of contrasts between riffles and pools, and disappearance of islands, bars, and beaches. High flows may also bring increased turbidity and decreased water quality.

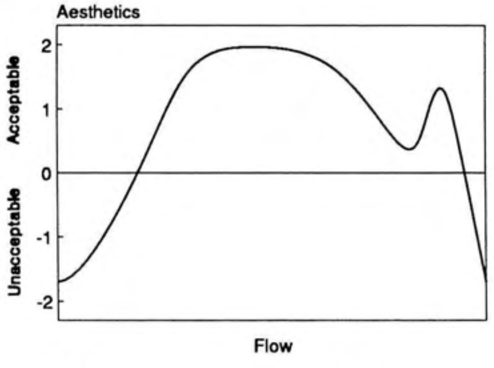

Figure 55. Hypothesized relationship between flow and aesthetics.

In general, the relationship between flow and aesthetics is probably as depicted in Figure 55. Aesthetics increase with flow to some point, then drop off at higher flows. Although we have not seen the issue addressed in the scientific literature, we think there may also be some aesthetic value associated with flood flows; perhaps people just appreciate the novelty and raw power of floods. Even here, however, one would expect the aesthetic quality to decrease at some point (perhaps where the flood becomes destructive).

Key Issues

Evaluating flows for aesthetics requires consideration of at least two issues.

- The quality of aesthetics at different flows may differ depending on the kind of recreation experience users desire. For example, whitewater boaters who like big hydraulics may evaluate higher flows as more aesthetic than hikers or anglers who need lower flows to wade or cross streams.

- Relationships between flows and aesthetics may differ on different segments of a stream. In general, for higher gradient and more boulder-strewn streams, the curve in Figure 55 would shift to the right (higher flows are needed) because aesthetics on these rivers tend to depend more on the sound, motion, and higher energy of high flows. On some low gradient streams, however, lower flows can result in vastly lower pool depths and particularly unaesthetic "bathtub rings." In these cases, the curve in Figure 55 would also shift to the left.

- Variation in flows may matter as much or more than any specific flow. Waterfalls in particular often have high aesthetic quality at a variety of flows. Delicate and graceful at low flows, a particular falls may feature powerful displays at higher flows and thus present quality aesthetics across the full range of flows. Because different falls depend to different degrees on power or grace for their scenic quality, appropriate evaluations of flows may require specification of the kind of falls desired.

Methods

The most useful techniques for evaluating aesthetics include user surveys and professional judgements. The aesthetic judgement of landscape architects has a fairly long history in resource management, and relatively elaborate assessment systems have been developed to help quantify and add rigor to those judgments. As with any professional judgment, however, experts may misrepresent the preferences of recreation users, the "clients" for whom aesthetic resources are being provided.

When possible, user surveys offer another way of evaluating the aesthetics of flows. Among the various survey methods, on-site efforts that ask about present flows are generally the more appropriate than flow comparison surveys because few people seem able to identify or remember flows they may have seen in the past, let alone specify their preferences for the aesthetics at those different flows. If the single flow survey approach is used, however, it needs to be conducted through a full range of flows to adequately describe how aesthetics change through that range.

In many cases an on-site survey of this nature may be difficult to conduct. An alternative method is to use photographic media (e.g., slides or video sequences) to represent aesthetic conditions at different flows and then ask recreationists to react to them. Research has shown that these kinds of efforts provide results similar to those of surveys conducted in the field, although considerable care needs to go into the way those studies are conducted (see pages 42). Controlled flow studies provide an excellent opportunity to explore aesthetic issues directly, as well as to photograph conditions for later evaluations by users (via surveys) or aesthetic experts such as landscape architects. The best studies will utilize a variety of techniques to document relationships between flow and aesthetics.

Figure 56. The aesthetics of the river environment often depend on flow. Sound, motion, and the sense that the river is alive increase with flow.

References and Suggestions for Further Reading

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Notes:

Chapter 7
INTEGRATING FLOW NEEDS

In nearly all situations where managers have control over flows, there are competing water uses. There may be different needs for different types of recreation, or there may be needs for non-recreation instream uses (e.g., maintenance of fish habitat, riparian vegetation, or channel form), or out-of-stream uses (e.g., irrigation, municipal water supply, or hydropower). Needs can be met in a variety of ways, with different combinations of flows at different times. Considering alternative flow scenarios is a useful way to think about the consequences of different management regimes, each of which produces unique combinations of resource outputs and benefits.

Multi-objective decision-making is a complex field which we do not intend to discuss in detail here. However, it makes sense to lay out a general strategy for developing alternative flow scenarios and consider a brief example from Colorado's Dolores River (Vandas et al., 1990).

Choosing an appropriate flow scenario that optimizes resource values on a river can be difficult. The obvious goal is to maintain natural values of the river and provide high quality recreation opportunities within the constraints of limited water availability. In many instances, however, this will require choosing between competing resources. The four steps outlined below suggest one process for exploring alternative integrations.

REVIEW FLOW REQUIREMENTS

The first step in developing alternative flow regimes is to review flow needs for specific opportunities or other resource outputs. In this step, flow needs should be boiled down to threshold levels (a single flow request for each) recognizing the incremental nature of most flow-quality relationships. These threshold flow needs should also be associated with a season when appropriate. Flow needs for various resource outputs on the Dolores are given in Table 6.

Table 6. Required flows to protect or provide resource outputs on the Dolores River, Colorado.

Resource Output	Flow Need
Canoe-fishing	125 cfs
Scenic canoeing	300 cfs
Scenic rafting	800 cfs
Minimum whitewater	1,100 cfs
Optimum whitewater	2,000 cfs
Channel maintenance	2,000 cfs 7 days
Rainbow trout spawning	125 cfs April-June
Brown trout spawning	65 cfs Sept.-March
Other fish maintenance	50 cfs July-Aug.

REVIEW MANAGEMENT CONSTRAINTS

The second step in the process is to review the constraints on providing various flows, whether they are natural (availability of water at various times during the year) or human (dam operation considerations, reservoir capacity, existing diversionary water rights, etc.). The idea is to determine the available "water budget." The assumptions and conditions considered when developing the Dolores River flow scenarios are presented below:

- Incremental changes in flows cannot exceed 500 cfs per day because of dam operation guidelines.
- The typical amount of water that will be released from McPhee Dam in an average year is estimated at about 105,000 acre-feet. In a slightly wet year, or with the possibility of changes in water use in a normal year, 130,000 acre-feet may become available. All flow scenarios will be developed with this range in mind.

- ❑ When flow needs for more than one resource output overlap during any portion of the year, the highest flow will be used.

- ❑ Annual peak flows have historically occurred in the late spring and should continue to be released then. Recreation users generally expect the highest flows during late April and May as well.

- ❑ State and federal agencies are already committed to the maintenance of the rainbow and trout fishery on the river and those flow needs have priority over recreation needs (fishery flows must be provided first).

OVERLAY FLOW REQUIREMENTS

The third step is the heart of the process: overlaying the various flow needs to find out which are compatible and which are competing. The task is a little like trying to combine pieces from several different jigsaw puzzles into a single coherent image. In order to make it work you may have to shave a few of the pieces and have a good sense of the kind of picture you want to create. Five scenarios for the Dolores given below illustrate different ways that particular puzzle could be put together. Table 7 summarizes the flows provided by each scenario.

Scenario A provides the **fishery maintenance** requirements as dictated by management constraints. Maintaining the biotic resource was considered a starting point for recreational quality on the river. Figure 58 shows an annual hydrograph that provides for fishery needs over the course of the year. This scenario uses 56,000 acre-feet, leaving somewhere between 49,000 and 74,000 acre-feet unused, depending on the water year and water rights negotiations. Providing **only** these fishery flows is unlikely because significantly more water must go down the river to meet downstream water rights obligations, but we presented the scenario for contrast. The fish flows also provide three months of "canoe-fishing" (April through June).

Scenario B added the **channeland riparian maintenance** flows to the fishery flows (Figure 59). These bankfull flows for a week are only needed every other year to flush out fine sediments from fish spawning areas, prevent tributary sediments from severely aggrading the channel (and increasing navigation problems over the long run), and to nourish riparian vegetation zones. However, because they require such a large amount of water, they leave relatively little room to provide for other outputs. The total amount of water required for Scenario B was 97,000 acre-feet, leaving between 8,000 and 33,000 acre-feet for other outputs. The week-long bankfull flows, however, also provide optimum whitewater opportunities during that period, and the 125 cfs fish flows from April through June offer canoe-fishing opportunities.

Figure 57. Canoeing on Colorado's Dolores River. Integrating flow needs for this or other resource outputs requires careful consideration of alternative flow scenarios.

Scenario C, the first to specifically provide for recreation, was developed with a **whitewater boating** emphasis (Figure 60). It was designed as a slight variation on Scenario B. The idea was to utilize the majority of water remaining from the fishery and channel/riparian maintenance flows to provide whitewater opportunities. Because the channel/riparian flows provide optimum whitewater, most of the remaining flows were designed to provide minimum whitewater. A small amount of water was also provided for both scenic rafting and scenic canoeing, so that all opportunities are available for at least a few days each year. Under this scenario, whitewater boating is provided for 21 days (seven days of optimum whitewater; 14 days of minimum). The scenario utilizes the full 130,000 acre-feet potentially available. Once again, fish flows provide a canoe fishing opportunity.

Scenario D, in contrast, emphasizes **scenic boating** (Figure 61). It cannot be provided unless channel/riparian maintenance and optimum whitewater flows are foregone (this could happen every other year). In this case, a very short period of minimum whitewater is provided (five days), but the vast amount of unused water remains to be divided for scenic rafting and scenic canoeing. Because these opportunities require less water per day, they can be provided for more days, considerably increasing the length of the boating season (see Table 7). The scenario also uses up the entire potential water budget (130,000 feet). The fishery flows again provide for canoe fishing from April to June.

Finally, **Scenario E** was designed to try and balance the **scenic and whitewater boating** needs even though optimum whitewater (and channel/riparian maintenance needs) are foregone (Figure 62). This provides a mix of recreation opportunities for a longer season (see Table 7), but recognizes that the very best conditions for one opportunity simply cannot be provided. The scenario also utilizes the entire potential water budget.

DISCUSS TRADE-OFFS

The final issue in developing flow scenarios is to explicitly identify the trade-offs they imply. Table 7 is an example of one useful device for showing these differences, but they should be discussed in the accompanying text as well. Decision-makers should clearly understand what they are getting by choosing one scenario over another. The text can also suggest that scenarios are only **alternatives** used to illustrate trade-offs. In fact, there are an almost infinite number of ways to allocate water to provide or protect various outputs. The scenarios are only starting points for discussion and negotiation among competing water users and decision-makers. The text below illustrates a trade-off discussion from the Dolores study.

Providing Channel and Riparian Maintenance Flows

Given current water availability, providing the flows necessary to maintain channel form and function as well as nourish riparian vegetation means relatively high flows for relatively short periods. While these kinds of dam releases help maintain and enhance some components of both fishery and recreation outputs, they do not leave much water for other outputs. While channel/riparian maintenance flows are required to maintain the river's natural integrity, they are only required every other year on average. In addition, it should be recognized that the authorization and construction of McPhee Dam has already significantly modified the river's natural balance and these flows are only designed to maintain a semblance of the existing natural system. In order to help illustrate how channel maintenance flows would trade-off with other outputs, two scenarios have been developed with the channel maintenance flows (B and C), while the other three have been developed without them.

Protecting Fishery Resources

Flows required to maintain fish habitat are relatively low, but the need to maintain those flows throughout the year means that the

Figure 58. Scenario A, flows for **fishery maintenance** (requires 56,000 acre-feet of water).

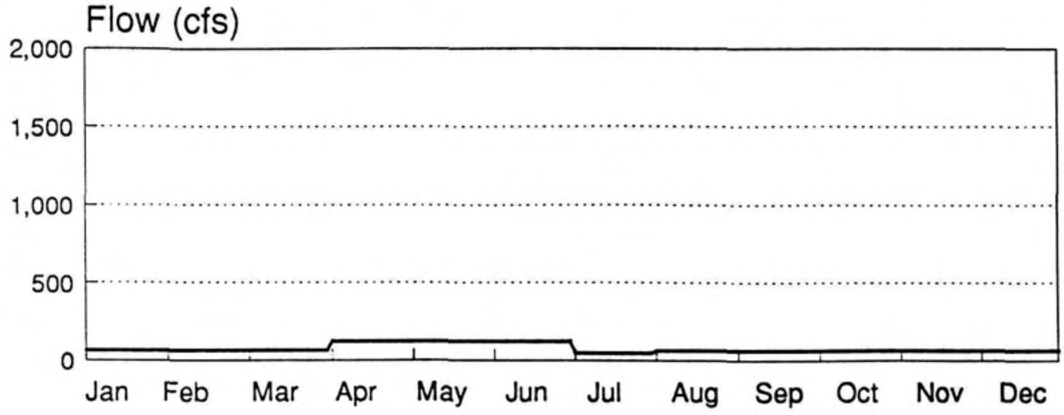

Figure 59. Scenario B, flows for **fishery and channel maintenance** (requires 97,000 acre-feet of water).

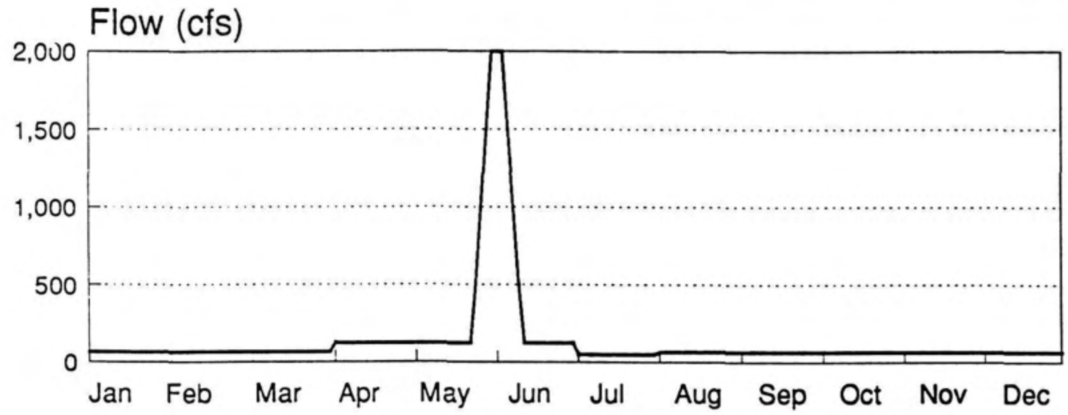

Figure 60. Scenario C, flows for fishery and channel maintenance, and a diversity of recreation opportunities (emphasis on **whitewater boating**).

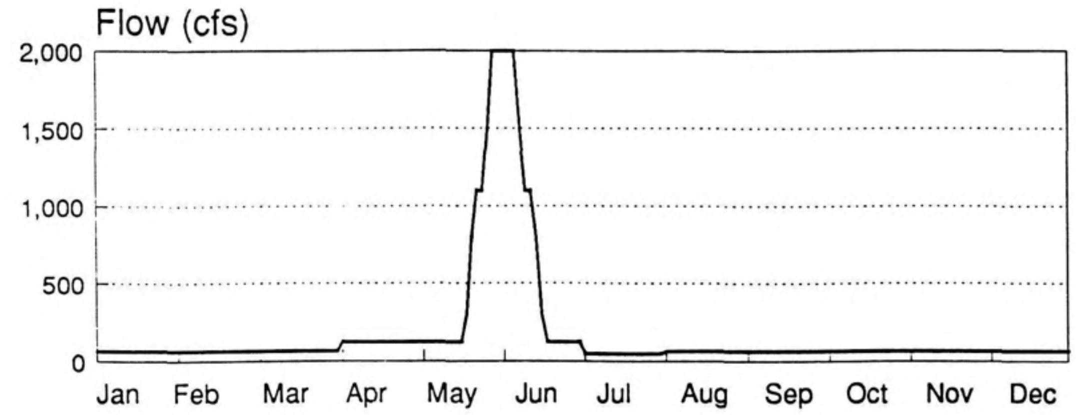

Figure 61. Scenario D, flows for fishery maintenance and a diversity of recreation opportunities (emphasis on **scenic boating**).

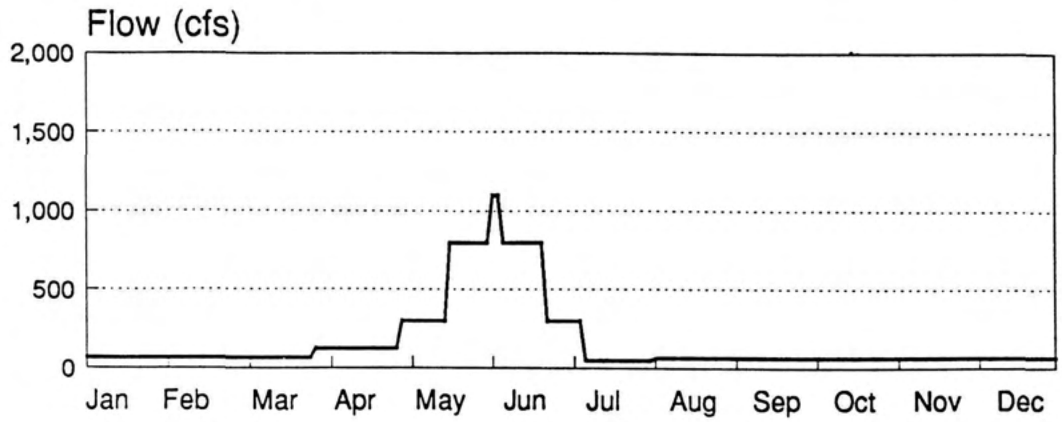

Figure 62. Scenario E, flows for fishery maintenance and a diversity of recreation opportunities (mixed emphasis on **whitewater and scenic boating**).

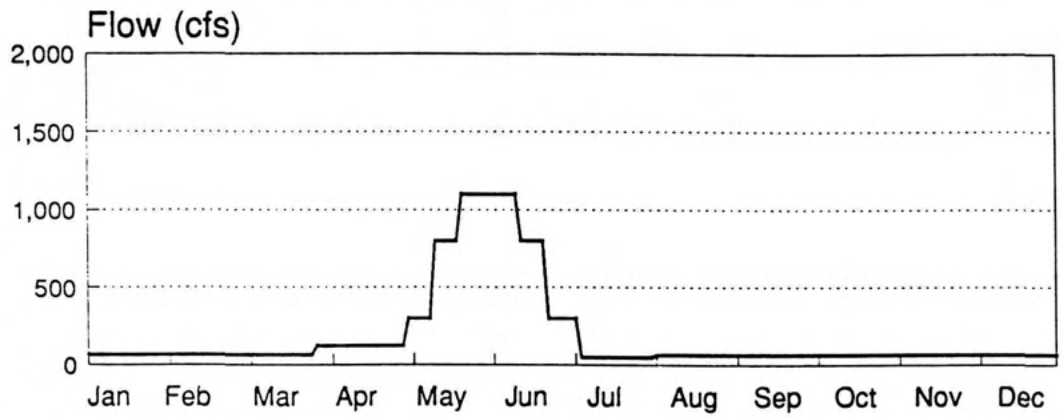

Table 7. Comparison of recreation season lengths (number of days) for various opportunities under the five flow scenarios.

Opportunity	Fishery Maintenance	Channel Maintenance	Whitewater Boating	Scenic Boating	Scenic & Whitewater
Canoe fishing (125 - 300 cfs)	91	78	60	32	35
Scenic canoeing (300 - 800 cfs)	0	2	5	32	22
Scenic rafting (800 - 1,100 cfs)	0	2	5	32	22
Min. whitewater (1,100 - 2,000 cfs)	0	2	11	5	22
Opt. whitewater (2,000 + cfs)	0	7	10	0	0
Total season (> 125 cfs)	91	91	91	101	100
Rafting season (> 800 cfs)	0	11	26	37	43
Whitewater season (> 1,100 cfs)	0	9	21	5	21

cumulative effect is relatively large. In addition, long-term enhancement of the fishery probably requires the channel maintenance flows described above. Taken together, these flows utilize a sizable amount of water relative to current availability, leaving only moderate amounts for other outputs. Almost all of the water currently available, for example, would be needed to provide both channel maintenance and fishery flows in the same year, leaving hardly any water for recreation opportunities. However, required flows for fish fully cover required flows for canoe fishing while the required flows for channel maintenance providea short period of optimum whitewater conditions. Forgoing fishery flows would free more water for recreation, although this would mean loss of the artificially induced non-native fishery that currently thrives as a result of year-round flows from McPhee Dam. Because loss of the fishery was not an acceptable management alternative for the Dolores (see management constraints), each of the scenarios included fishery flows. For comparative purposes, one scenario shows only the required fishery flows.

Providing Recreational Opportunities

Given the water availability constraint of 130,000 acre-feet, providing whitewater opportunities means that boating seasons are generally short and there is little water for other kinds of recreation opportunities (excluding the canoe-fishing opportunity provided by fish flows). In contrast, providing scenic boating opportunities means relatively lower flows over a much longer season, but very little water for whitewater opportunities. In order to illustrate some of these differences, three recreation scenarios have been developed, one providing primarily whitewater opportunities (C), one providing primarily scenic opportunities (D), and one providing a combination of whitewater and scenic opportunities (E). All three scenarios provide fishery flows, and the whitewater scenario provides channel/riparian maintenance flows as well.

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Notes:

Chapter 8
FLOW PROTECTION STRATEGIES AND NEGOTIATION

Once various flow scenarios have been developed and assessed, it becomes necessary to choose and/or negotiate a preferred alternative or implement a flow protection strategy. Depending on the situation, there may be any number of management options that will protect or provide desired flows; understanding these options is critical for deciding how to insert recreation information into the negotiation process.

Flow protection options can be generally classified into three categories:

- The acquisition of **instream water rights** or use of other legal mechanisms that protect existing flows from out-of-stream uses (withdrawals and diversions).
- The modification or regulation of **dam operations**, the use of a variety of legal or administrative mechanisms to guide or direct operation of a dam or similar water resources project and thus provide certain downstream flows.
- The acquisition of **ground water rights** or similar legal mechanisms that protect ground water supplies (useful for arid streams where instream flow is intimately tied to ground water tables).

Within each category there are a variety of state and federal laws, legal case histories, administrative rulings, and agency policies that may apply. A detailed discussion of each is out of the scope of this handbook (see the references at the end of the chapter for more information). The following discussion, however, briefly discusses some options within each category and the most issues involved with them.

INSTREAM FLOW WATER RIGHTS

States have the authority to administer water resources within their boundaries. In the western states, the prior-appropriation doctrine is the primary basis for allocating water supplies; in eastern states, the riparian doctrine applies. It is useful to consider each of these separately.

Western Water Rights

Rights to appropriate water in western states are keyed to the concept that it will be put to a "beneficial" use. States have discretion in defining which beneficial uses are recognized. Assuming appropriators put water to beneficial uses, their rights to available water supplies is dependent upon the date to which they first put the water to that use; "first in time, first in right."

The concept of a "priority date" is fundamental to the doctrine. If supplies become diminished, prior-appropriators are granted their entire rights before "junior" appropriators. Holders of junior rights, however, can block transfer of senior rights if they will impact water supply conditions and injure their rights. Water rights can be sold or transferred. Also, they can be forfeited if a period of time lapses when the right is not used.

In more recent times, most western states have come to recognize certain instream uses of water as "beneficial" uses under state law. In certain states such as Alaska, instream beneficial uses are broadly defined and include rights for recreation and navigation. In other states such as Colorado, instream beneficial uses are more narrowly defined for fish and wildlife uses alone. In any case, if state appropriation doctrine is considered as a flow protection mechanism, it is important to frame flow needs in terms of state-recognized beneficial uses. Since instream water rights acquired in current times may have ineffective priority dates, it may also be necessary to investigate acquiring or transferring existing water rights to instream uses.

Eastern Water Rights

In eastern states, which are guided by the so called "riparian rights doctrine," water of almost any amount is allocated to any adjacent landowner as long as it is put to "reasonable use." This sort of system has worked relatively well given the general abundance of water in most eastern states, but in recent years that abundance has been tested. Increasing controversies over water use in the east, including increasing comprehension of the connection between water quality and water quantity (instream flow), have led to the development of laws in several states that essentially regulate the use of water and establish de facto minimum instream flows (Bailey, 1992).

While there are limits to these sorts of state regulations, which do not create a direct legal mechanism such as the western instream water right, they suggest a trend toward more formal protection. Some observers predict that some sort of allocation system will be developed over time in eastern states as well, but the legislative, administrative, and legal battles over this system are unlikely to be resolved in any consistent or elegant way in the near future (Sherk, 1992).

Instream flow protection is likely to be at the heart of some of these battles and the emerging allocation systems may offer both opportunities and threats. In either case, well-conducted flow assessments will be critical for understanding the implications of allocation decisions.

Federal Water Rights

While both eastern and western water law is keyed to state's rights, there are certain situations where federal law may diminish state rights to appropriate water. These situations occur when the federal government sets aside public domain for specific purposes such as Indian Reservations, National Forests, Wild and Scenic Rivers, National Parks, or other purposes. The courts have ruled that when these reservations of public land occur, there is an implied right to sufficient water supplies to permit the primary purpose of the reservation to be realized. These court rulings have created the concept of "Federal-Reserved" water rights, i.e., water rights which exist as separate from state water law. When rivers are part of specific reservations of the public domain, there may be a basis for a Federal Reserved water right with a priority date set at the date of the reservation. In all cases, Federal rights can not impact state rights of earlier priority date.

Figure 63. Alaska state law recognizes instream flow water rights for recreation. An increasing number of states are adopting similar laws.

It is also useful to note that federal legislation also can impinge on state rights to administer water in cases where large Federal water projects (i.e., dams) are authorized with the expressed purpose of putting water to specifically identified purposes. Because of the controversy which often accompanies the concept of "implied" Federal water rights, Congress (at least in recent years) is generally careful to address federal water rights in legislation intended to reserve public domain or to implement water-dependent federal projects.

MODIFICATION OF DAM OPERATIONS

Many of this country's rivers have their flows regulated by upstream dams. Most of these dams were constructed by the federal government (as part of water development, flood-control, or navigation projects by the Bureau of Reclamation, Corps of Engineers, Tennessee Valley Authority, or Bonneville Power Administration), or they were and are licensed by the federal government through the Federal Energy Regulatory Commission (FERC). Because many dams were built long ago without preparation of detailed environmental impact assessments, the effects on their design and operation on upstream and downstream resources were never systematically evaluated. In recent years, under increasing pressure from advocacy groups and congressional direction, these agencies have indicated a willingness to reconsider dam operations that primarily focus on flood control, hydroelectric power, or irrigation and establish operations that balance those primary purposes with downstream recreation and environmental values.

With the Bureau of Reclamation or Corps of Engineers projects, recreation or environmental advocates may be able to directly negotiate with dam managers and the out-of-stream users that depend on a river's water (irrigators, municipalities, or power companies). With other agencies and privately operated dams, advocates are less likely to be able to establish direct negotiations unless the dam is going through the FERC re-licensing process. However, as mentioned in the introduction to this handbook, over 200 major dams will be re-licensed over the next decade and there may be a number of good opportunities to assess and then protect instream flow needs for these downstream values. FERC has been directed by federal law to consider downstream resources such as recreation during the process, and with direction from the Congress, the National Park Service has established an assistance program to help represent recreation interests in the process as well.

Figure 64. Glen Canyon Dam upstream of the Grand Canyon on the Colorado River. Modifying dam operations is another way to provide flows for recreation outputs.

In a few cases, legislative mandates such as the Endangered Species Act may also provide opportunities to review and modify dam operations to benefit recreational resources. At Flaming Gorge Dam on the Green River in Wyoming, release patterns have been modified by the Bureau of Reclamation to benefit downstream endangered fishes. Similarly, downstream water rights may provide opportunities to secure certain modifications in release regimes. Finally, such as is presently the case with the Glen Canyon Dam on the Colorado River, there may be opportunities to bring agencies responsible for dam operations and natural resource management together to negotiate changes in dam release patterns to enhance the variety of downstream recreation, cultural, and natural resources.

Several dam release variables can be modified to benefit downstream resources. However, there may be legislative and administrative constraints related to other dam purposes which restrict flexibility to manage for downstream resource values. Minimum flow releases can often be established for such values as fisheries. Controlled high flow releases can also be designed to benefit flood-dependent riparian, geomorphic, and aquatic resource amenities. Maximum annual release levels can be prescribed to protect downstream cultural and sediment resources. Finally, daily discharge fluctuations associated with peaking power can be constrained to avoid adverse downstream impacts. Manageable daily flow variables include daily discharge range and rates of discharge change (ramping rates).

To effectively achieve modifications in dam operations to enhance downstream recreation and natural resource amenities, it is first necessary to be a "player at the table." The reasons for participating in dam operations planning may be legislated or negotiated. In any case, it is best to bring all parties with an interest in dam operations together as early as possible in the planning process. Also, for those who advocate downstream natural resource enhancement, it is very important to come to the table with an understanding of the available "management space" (the administrative and legal constraints on possible management options) and avoid asking for the world. Many dams have been built unadvisedly and have had major adverse impacts on downstream values. However, many of these same dams also provide a number of other important outputs demanded by society. Expecting recent understanding of these impacts to guarantee dam modification is unrealistic. Advocates still face an uphill struggle to make their case and should be sure to base that case on defensible resource objectives.

GROUND WATER RIGHTS

In parts of the United States such as the desert southwest, many streams maintain perennial flow because of ground water inputs from regional aquifers. In fact, it is the intimate relationship between these streams and their regional aquifers which distinguish them from the more typical ephemeral desert wash. While baseflows may be low in desert streams, they are critical because of the unique and prized aquatic and riparian resources they sustain. When regional ground water is identified as a critical element in protecting instream flow-dependent amenities, it is important to develop appropriate information to address ground water needs and to identify opportunities to achieve or protect necessary ground water conditions.

In general, arid-land streams tend to lose flow to alluvial groundwater unless the water table is maintained at the elevation of the surface stream. In assessing ground water conditions it is important to know where the ground water is in relation to the stream and the rates of gain and loss to and from groundwater. When groundwater recharges surface streams, it is very important to maintain water table elevations. Where upstream reservoir releases are to be used to sustain perennial flows, dam releases can also be designed to counter downstream loss rates.

Figure 65. Ground water pump near the San Pedro River, Arizona. Protection of aquifers may be needed to maintain surface flows in arid areas.

Once ground water protection needs are identified, it will probably be necessary to work with individual states in framing a meaningful protection strategy. Many states appropriate "connected" ground water within the context of their appropriation laws, and pumping rights can, in fact, injure the rights of senior surface appropriators. In addition, other states such as Arizona have ground water management laws which may provide a vehicle for achieving ground water protection. In any case, it may be incumbent upon river management interests to insure, through monitoring, that ground water protection objectives are being achieved.

FINAL COMMENTS ON NEGOTIATING FOR RECREATIONAL INSTREAM FLOWS

Legislation and government policy on both the state and federal levels has increasingly recognized the importance of maintaining or providing instream flow in rivers for recreation over the past 25 years. However, this recognition alone does not create flow protection, it only sets up the opportunity for protection. Laws and policies need to be actively applied and managed to be successful. Similarly, a well conducted study of instream flow needs for recreation cannot guarantee protection either. Instream flow advocates also need to successfully insert the information from the study into the water allocation process. While much of this handbook has focused on the science involved in determining required flows for recreation, the science is pointless until it has been used to protect flows with a legal, enforceable, and administratively manageable mechanism.

Regardless of the type of legal or administrative "hook" (law or policy) that one pursues as part of the strategy to protect flows, the common element in any flow allocation process seems to be the "negotiated solution." Whether applying for a state water right, defending a federal reserved water right, or intervening in a FERC re-license, the ultimate goal is an agreed-upon solution among all water users. While in some cases it may make sense to fight for flows in the courts, negotiated solutions that fairly balance competing flow needs seems a preferable approach. In order to help facilitate these kinds of negotiations, it is important that recreation managers, researchers, and advocates become "players at the table" and avoid more adversarial roles. By presenting rational and objective information about flow needs or the consequences of not meeting those needs, recreation interests are likely to be well served. The Dolores River provides an example of this idea. America Outdoors, an organization of commercial rafting companies, was able to use study results from the BLM report to successfully negotiate recreation flows on the river.

As with many of the subjects covered in this handbook, a word of caution is appropriate. Developing and implementing a flow protection strategy, (i.e., participating in a flow negotiation process) can be very complex. In order to do this job well, it often pays to bring in people who have skills and experience in the area. Consultation and assistance from lawyers, planners, and other professionals with expertise in consensus-building can prove invaluable with many rivers. The Rivers, Trails, and Conservation Program of the National Park Service also may be able to help in this regard. In addition to supporting publications such as this handbook, the program provides assistance to state, federal, or local organizations interested on the conservation of river resources, including instream flows for recreation.

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Notes:

Appendix A
RECOMMENDED OUTPUT FROM FLOW-RECREATION STUDIES

Preceding chapters in this handbook focused on the ideas and issues involved in conducting and using instream flow assessments for recreation. This appendix presents a list of specific outputs we would like to see produced in future studies in order to advance the field. As noted in the introduction, many studies are relatively narrowly focused on a single river or small number of recreation activities and thus cannot be compared to other similar studies. But if we can make studies more comparable (as well as publish their findings so others may benefit from them), it may be possible to develop more generalizable models. The list begins with the basic hydrology descriptors studies should identify, continues with the ways recreation flow needs should be reported, and concludes with recommended presentations of channel and riparian vegetation flow needs.

HYDROLOGY INFORMATION

Mean annual flow, the total amount of water passing by a point over the course of a year, is the most basic hydrology descriptor that should be reported in a study. Annual flow is the independent variable in Tennant or Corbett-type calculations and provides a useful single indicator of a river's size.

Bankfull flow, indicating flow during a two-year recurrence flood, is another extremely useful hydrology descriptor. This variable is another single indicator of a river's size, and we suspect Tennant or Corbett-type models using this variable as the independent variable may prove even more powerful than ones using mean annual flow.

An annual hydrograph is also critical. While mean monthly flows are often sufficient here, median daily flows may be more useful, particularly on arid-land streams. We suggest reporting both.

A river classification provides a simple way to indicate the type of river where the study was done. The Rosgen classification system (see reference in Chapter 4) is particularly useful in this regard, although a more generic description of the stream may suffice.

Finally, **dam operation guidelines** should be reported whenever there is an upstream project. A number of hydrologic or recreation issues may depend upon the way a dam is operated, and research consumers will need to understand those to put other research findings in context.

RECREATION INFORMATION

An overall flow preference curve for each opportunity is the most critical information studies should provide. These show how recreation quality varies over the full range of flows, and they should be developed separately for each kind of recreation that requires different flows. If a curve cannot be developed, researchers should at least identify threshold "marginal flows" (when about equal numbers of users report that flow-dependent recreation quality is acceptable and unacceptable; when flow preference curves cross the neutral line), as well as "optimal flows" (when strong majorities of users report or would report flow-dependent recreation quality as acceptable; the peak of a flow preference curve). Incidentally, once these two flows have been identified, there really is no point in avoiding developing an incremental curve based upon them. The two points by themselves prescribe an implicit curve as it is; drawing the curve simply makes this relationship explicit. Reports should also make clear whether the curve is based on professional judgement, survey data, models, or other methods.

Studies also need to **identify specific flow needs for various attributes** that go into developing the overall flow preference curves. This information might relate flows to boatability, whitewater, rate of travel, swimmability, fishability, aesthetics, etc. and ideally would be presented as incremental curves. However, this information can also be discussed in terms of threshold flows. For each of the following attributes, there are a couple of key issues to address so research can be compared from different rivers:

- ❑ Boatability: Specify marginal and optimal flows for different craft. Be sure to define assumptions in regard to craft size and loading, as well as the skill of operators. Also define tolerances for specific boatability conditions such as hits, stops, drags, and portages.

- ❑ Whitewater: Specify marginal and optimal flows for different craft and skill levels. Make sure to separate challenge issues from safety issues.

- ❑ Fishability: Specify marginal and optimal flows for different kinds of fishing. List species users fish for as well as any information about the way they fish (fly fish in riffles or pools, spin cast into holes, etc.).

- ❑ Swimmability: Specify marginal and optimal flows for different kinds of swimming. Make sure to define the kind of swimming and provide information about where this takes place (in pools, through rapids or riffles, etc.). Also define the skill of swimmers.

- ❑ Aesthetics: Specify marginal and optimal flows and discuss the way features change with flow levels.

CHANNEL AND RIPARIAN INFORMATION

Report **recommended flow needs** to maintain environmental conditions in terms of cfs and as a percentage of mean annual flow and bankfull flow. We suspect that useful rule-of-thumb models for required flushing or flood flows may emerge from an examination of such data.

Report the **link between recommended flow needs and the conditions they are intended to maintain.** Studies should explicitly identify which important environmental conditions are at issue and how recommended flow regimes will work to protect them. The consequences of not providing recommended flow regimes should also be discussed in as specific terms as possible.

Appendix B
EXAMPLE SURVEY QUESTIONS

The following appendix contains a list of example questions for surveys of recreationists or expert users. Readers are cautioned from simply copying the questions when conducting their own surveys; some of these questions obviously do not apply to all rivers or all kinds of recreation experiences and many may need to be modified to fit a particular situation. However, if some questions can be used verbatim it will be possible to compare results from different rivers and increase our collective research knowledge. Some questions are appropriate for **flow comparison surveys** (where users are sensitive to flows and conditions and can answer questions about a range of flows) while others are designed for **single flow surveys** (where users respond to the specific flows and conditions they just experienced). The two kinds of questions are presented separately.

ALL SURVEYS

1. What kind of craft do you use (did you use) on the river?
   - ❑ Drift boat
   - ❑ Small raft (14 feet or less)
   - ❑ Large raft (over 14 feet)
   - ❑ Open canoe
   - ❑ Kayak or decked canoe
   - ❑ Jetboat
   - ❑ Small powerboat (less than 40 horsepower)
   - ❑ Large powerboat (40 horsepower or more)
   - ❑ Other ______________________

2. How many trips have you taken on the river?

   _____ trips

   or....

   How many years have you been taking trips on the river?

   _____ years

3. Are you an outfitter, guide, or private river user?
   - ❑ Outfitter
   - ❑ Guide
   - ❑ Private user
   - ❑ Other _________________________

4. How would you rate your own skill level?
   - ❑ novice (no previous boating experience)
   - ❑ beginner (some previous boating experience)
   - ❑ intermediate
   - ❑ advanced
   - ❑ expert

FLOW COMPARISON SURVEYS

1. Is flow or water level information available to you?
   - ❑ Yes
   - ❑ No

2. Do flow levels influence whether or not you take a trip?
   - ❑ Yes
   - ❑ No

3. Do flow levels influence ***how*** you take trips (when you go, what craft you use, which rapids you run, how much gear you take, etc.)? If yes, please describe below.

   ____

   ____

Now think more specifically about how flows affect the quality of your trips and the threshold flows which provide certain kinds of conditions. Assuming a constant water level for the duration of a trip, try to specify flows for each of the following.

4. Think of the river as a waterway being used for transportation. What is the minimum water level you need to get down the river?
   _____ cfs or stage

5. What is the optimum or best water level for getting down the river?
   _____ cfs or stage

6. At low water levels, users sometimes **hit** (make contact with the bottom or rocks in the river), get **stopped** (become stuck on a rock or the bottom), have to **boat drag** (get out of their boat to pull it off the bottom or rock, or **portage** (carry their boat around a shallow area or obstacle). How many times per day would you be willing to experience each of these kinds of boatability problems per day before your trip was compromised?

   I would be willing to hit bottom _____ times per day
   I would be willing to be stopped or grounded _____ times per day
   I would be willing to have to drag my boat off an obstacle _____ times per day
   I would be willing to line or portage around obstacles _____ times per day

7. What is the lowest water level you consider acceptable for a minimum quality whitewater experience?
   _____ cfs or stage

8. What water level provides the highest quality whitewater experience?
   _____ cfs or stage

9. What is the lowest water level that provides a safe run?
   _____ cfs or stage

10. What is the highest water level that provides a safe run?
   _____ cfs or stage

11. What is the highest flow you would consider running?
_____ cfs or stage

12. What is the lowest water level that provides a reasonable rate of travel on the river?
_____ cfs or stage

13. Below what flow level do the aesthetics or scenic quality of the river begin to decline?
_____ cfs or stage

14. Above what flow level do the aesthetics or scenic quality of the river begin to decline?
_____ cfs or stage

15. What is the lowest flow level that provides good fishing conditions?
_____ cfs or stage

16. Which of the following reasons helps explain why the fishing declines below that flow? *(Check all that apply).*

- ❑ Fish are too inactive
- ❑ Water temperatures are too high
- ❑ Water is too clear; fish are aware of anglers
- ❑ Other ____________________

17. What is the highest flow level that provides good fishing conditions?
_____ cfs or stage

18. Which of the following reasons help explain why the fishing declines above that flow? *(Check all that apply).*

- ❑ Water is too turbid or muddy
- ❑ Difficult to wade at best fishing holes (too deep and fast)
- ❑ Water is too fast for the kind of fishing I do
- ❑ Other _______________

19. What is the lowest flow level that provides good swimming conditions?
_____ cfs or stage

20. Which of the following reasons help explain why swimming quality declines below that flow? *(Check all that apply.)*

- ❑ Pools are too shallow for swimming
- ❑ Pools are too shallow for diving
- ❑ Current is too slack; I enjoy swimming through riffles and rapids
- ❑ Pools begin to look stagnant
- ❑ Other ____________________

21. What is the highest flow level that provides good swimming conditions?
_____ cfs or stage

22. Which of the following reasons help explain why swimming quality declines above that flow? *(Check all that apply.)*

- ❑ Pools are too deep
- ❑ Current is too fast
- ❑ Not enough beach or shore is exposed for enjoying the river
- ❑ Other ____________________

Finally, we would like you to give an overall evaluation for the range of water levels available on the river. Make this evaluation based upon the type of trip you specified in the first part of the survey. In making the evaluation, try to give consideration to all of the conditions that make up a high quality trip, including navigability, whitewater, rate of travel, fishing, swimming, etc. Circle one number for each flow.

	Totally Unacceptable	Unacceptable	Neutral	Acceptable	Totally Acceptable
50	-2	-1	0	1	2
100	-2	-1	0	1	2
200	-2	-1	0	1	2
300	-2	-1	0	1	2
400	-2	-1	0	1	2
500	-2	-1	0	1	2
600	-2	-1	0	1	2
800	-2	-1	0	1	2
1,000	-2	-1	0	1	2
1,200	-2	-1	0	1	2
1,500	-2	-1	0	1	2
2,000	-2	-1	0	1	2
2,500	-2	-1	0	1	2
3,000	-2	-1	0	1	2
3,500	-2	-1	0	1	2
4,000	-2	-1	0	1	2
5,000	-2	-1	0	1	2
6,000	-2	-1	0	1	2
7,000	-2	-1	0	1	2
8,000	-2	-1	0	1	2

Note: The range of flows given in the left had column will obviously need to be modified depending upon the size of the river. In this example we chose to ask about smaller increments at the low flow end of the continuum because we had other information to suggest we needed more information about those flows. Lacking this information, the increments should probably be consistently spread across the full range.

SINGLE FLOW SURVEYS

Please rate the flow or water level with regard to the following conditions:

	Flow or water level was.....					If unacceptable, was it...	
	Totally Unacceptable	Unacceptable	Neutral	Acceptable	Totally Acceptable	Too low	Too high
Boatability	-2	-1	0	1	2	❏	❏
Whitewater challenge	-2	-1	0	1	2	❏	❏
Whitewater safety	-2	-1	0	1	2	❏	❏
Rate of travel	-2	-1	0	1	2	❏	❏
Aesthetics	-2	-1	0	1	2	❏	❏
Fishability	-2	-1	0	1	2	❏	❏
Swimmability	-2	-1	0	1	2	❏	❏
Overall Evaluation	-2	-1	0	1	2	❏	❏

Note: The following questions are oriented toward floating use; many can be adapted to powerboating, swimming, fishing, or other kinds of river recreation.

1. Boatability problems can be put into four different classes as follows:

Hits: Any contact with the bottom or rocks in the river with no loss of forward momentum.

Stops: Contact with the bottom or rocks that causes the boat to stop its momentum, but which can be corrected little effort such as shifting weight, pulling hard on the oars, or pushing off with a paddle.

Boat drags: A grounding that requires boaters to get out of their boat and pull it off an obstacle.

Portages: When boaters have to carry or line their boat around obstacles or rapids because they are not runnable.

How many times did you encounter each of these types of boatability problems (today, on this trip, on this segment)?

I **hit** bottom _____ times
I was **stopped** _____ times
I had to **boat drag** _____ times
I had to **portage** ______ times

How many times would you be willing to experience each of these types of boatability problems (today, on this trip, on this segment) before your trip was compromised?

I would accept _____ **hits**
I would accept _____ **stops**
I would accept _____ **boat drags**
I would accept _____ **portages**

2. Check the response below that best depicts the overall water velocity or current speed in this reach....

- ❑ Still: no discernible current.
- ❑ Slight: current slightly discernible. I had to paddle/row to make reasonable downstream progress.
- ❑ Moderate: definite current. Strong enough to move boat downstream at an acceptable rate without paddling/rowing.
- ❑ Strong: solid current. Strong enough to move boat downstream at a reasonable pace. Strong hydraulics exist and some maneuvering is also necessary.

3. Which of the following things did you perceive to be a <u>problem</u> to navigation?

- ❑ narrow channel width
- ❑ exposed boulders or bedrock
- ❑ rocks just under the water surface
- ❑ exposed or shallow riffle areas
- ❑ submerged or partially submerged vegetation
- ❑ overhanging shoreline vegetation (sweepers/strainers)
- ❑ man-made obstacles such as bridge abutments, etc.
- ❑ other ______________________________
- ❑ there were no navigation problems in this reach

4. Based on your experience, note the level of difficulty in maneuvering your craft downstream, avoiding obstacles, and setting up for running riffle or rapid areas?

- ❑ easy
- ❑ moderately difficult
- ❑ difficult
- ❑ very difficult

5. Please rate the flow level you experienced on this reach today. Would you prefer a water level that was higher, lower, or about the same?

- ❑ much lower
- ❑ lower
- ❑ about the same
- ❑ higher
- ❑ much higher

6. Rate the overall suitability of this water level for boating in your craft....

- ❑ optimal
- ❑ acceptable
- ❑ marginally acceptable
- ❑ unacceptable

7. Given the opportunity to float this segment again in the future, under identical flow conditions, would you choose to return?

- ❑ yes
- ❑ no

8. What is the minimum skill level necessary to successfully run this segment at this flow level?

- ❑ novice (no previous boating experience)
- ❑ beginner (some previous boating experience)
- ❑ intermediate
- ❑ advanced
- ❑ expert

9. Were there a few "critical spots" at this flow level, and if so where?

- ❑ no
- ❑ yes ____

10. List the primary advantages of this flow....

____
____
____

11. List the primary disadvantages of this flow....

____
____
____

Appendix C
A BRIEF GLOSSARY OF TERMS

Aesthetics refer to the visual evaluation of physical conditions. For flow - recreation studies, the issue is evaluating aesthetic quality at different flow levels.

Attributes refer to specific characteristics of a recreation experience. With flow - recreation studies, the attributes of interest typically include, boatability, whitewater, rate of travel, swimmability, fishability, etc.

Boat drags refer to times when boaters have to physically get out of their boat and drag it across a series of boulders or a gravel bar. It is a more severe floatability problem than a stop. A typical boat drag means pulling the boat across several feet of obstacles. Even a few drags per day can be obtrusive. The term "extended boat drags" may be used to describe situations when recreationists must drag their boat across much greater distances than just several feet.

Boatability refers to navigation conditions for any type of boat. "Navigability" is not used because of possible confusion with that term's other connotations and legal definitions.

Canoe zero is a term used in the eastern United States to describe the minimum flow necessary for open canoe navigation. In many cases, canoe zero levels have been institutionalized through painted gauges on bridges. Corbett made canoeing zero estimates for 45 eastern and midwest streams to develop a model for predicting canoe zero from mean annual flow. The Corbett definition of canoe zero is based on no boat dragging (having to get out of your boat to get around or off obstacles); no more than three stops (having to shift weight in the canoe or push off with your paddle); and no more than two or three hits (simply making contact with the bottom, but not losing forward momentum).

Direct effects refer to impacts from a flow regime that are immediate and obvious. They are generally associated with the hydraulics of the river: the velocity of the current, the depth of pools or channels, the size of holes or waves, the amount of exposed beach, etc.

Fishability refers to the combination of conditions that create high quality fishing opportunities. Depending upon the river, fishability may be related to a number of different flow-related variables, including water clarity, access to good fishing areas (wadeability, "castability" from the bank, available conditions for successful backtrolling or drift-fishing, etc.), or potential fishing success (fish are active, schooled up in fishable holes or riffles, etc.).

Flow preference curves refer to the graphic relationships between flow (horizontal axis) and evaluations of recreation quality (vertical axis). In most cases, the curves show inverted U shapes -- extremely low flows and extremely high flows will provide lower quality recreation while medium flows will provide more optimal conditions. Flow preference curves technically refer to evaluations based on survey data although other methods may be used to develop them. In most cases, flow preference curves refer to relationships between flow and a specific recreation attribute such as navigation, whitewater, swimmability, or fishability. In other cases, however, the relationship is between flow and overall recreation quality. In order to differentiate the two, it is useful to call the latter an "overall flow preference curve." **Flow suitability curves** essentially describe the same relationships as flow preference curves, but they are developed from IFIM analyses (predictive modeling-based information) rather than survey-based methods.

A river's **flow regime** refers its hydrology throughout a specified period. The term is often used in a general way to describe a dam or diversion operating regimen. The specifics of the flow regime are represented by various hydrological variables such as mean annual flow, peak flow, minimum flow, flood recurrence interval, etc.

Flow scenarios are proposed flow regimes designed to provide or maintain certain flow needs for recreation or other values. Many flow - recreation studies will develop alternative flow scenarios to illustrate key trade-offs between different flow-dependent values.

Geomorphology is the study of the interactions of flowing water, sediments, and vegetation with stream channels. Beaches, bars, oxbows, sloughs, pools, riffles, and rapids are geomorphic features.

Hits refer to times when a canoe or raft hits a rock or gravel bar and is slowed or deflected but not stopped. Hits are the least obtrusive floatability problem.

Hydraulics refers to the behavior of flowing water in a channel. The hydraulics of flowing water thus invovle characteristics such as depth, width, velocity, etc.

Hydrology is the study of the distribution of water (in a river) over time. Hydrology tells you how much water and when.

IFIM or **Instream Flow Incremental Methodology** refers to a series of computer-based models that relate the amount of high quality fish habitat with different flow levels. The models are based on extensive data about habitat needs for various species on other rivers. The input is hydrology information from the river in question. Output includes incremental curves for specific species and life stages on that river.

Incremental curves refer to graphed relationships between flows or flow regimes and some flow-dependent value. IFIM produces incremental curves for fish habitat, showing how different flow levels create more or less habitat. Recreation instream flow analyses should also develop incremental curves as one output.

Indirect effects refer to the less immediate and long term effects of flow on resource conditions. In general these will focus on channel morphology and riparian vegetation issues. Indirect effects are often overlooked during instream flow analyses, but they can have important implications for recreation. Flows affect a river's environment over both the short and long term.

Instream flow analysis explores the effects of flowing water on values **through** the effects on hydraulics, geomorphic features, and riparian vegetation.

International Whitewater Scale is a standardized rating system for whitewater characteristics. The scale runs from Class I (flat water, low technical difficulty) to Class VI (strong currents, large drops, extremely difficult even for expert boaters).

Marginal flow refers to the flow level where conditions become barely acceptable for a given type of experience. With the classic inverted U-shaped flow preference curve based on survey data, the marginal flow is defined as the point when the curve crosses the neutral line, or when equal numbers of respondents report a flow as being acceptable and unacceptable. The quality of experiences provided by marginal flows is low and is in distinct contrast to more optimal flows.

Minimum flow is a commonly used term that has a similar definition to **marginal flow**. It refers to barely acceptable flows for a given type of experience. However, we discourage use of the term because of potential misuse by competing out-of-stream users. It is common, for example, for irrigation proponents to talk about the "minimum" amount of water they need to divert for crop production. But they don't really mean "minimum" when they use the term -- they are talking about the minimum diversion they need to produce an optimum crop, not just keep the crop just barely alive. Under this definition, minimum means "all that you need." A recreation study that thus identifies a marginal flow as the "minimum flow" may end up confusing negotiators into thinking that it will provide a quality recreation experience. Minimum flows do not provide high quality recreation.

Optimization methods refer to mathematical techniques that attempt to balance competing needs and provide the best combination of outputs. They can be useful in working out trade-offs between competing recreation opportunities or other uses of instream flow. The key to optimizing efforts is the development of the assumptions or how the various outputs will be weighed. The best optimization methods will make these assumptions explicit and explain how they were developed.

Optimum flow refers to the flow level that provides the best combination of resource conditions for a given recreation experience. It is a term that contrasts with marginal or minimum flows. When applied to the classic inverted-U flow preference curve, the optimum flow is at the peak of the curve. In many cases curves may be relatively flat, so there may be an optimum flow range rather single optimum flow.

Portages refer to times when boaters have to drag or carry their boat out of the channel and around some obstacle because of poor floatability conditions. This commonly occurs when there are river-wide sweepers, logjams, or significant rapids at low water conditions. In most situations, portages are extremely obtrusive navigation problems.

Rate of travel refers to the amount of time it takes to travel on a river at different flow levels. It is generally only an issue for floating users. Rate of travel is usually directly related to flow.

Resource conditions refer to the physical changes in the river environment, including the river's hydraulics, its riparian vegetation, and channel geomorphology. Instream flow studies explore the effects of flow on resource conditions.

Resource outputs refer to the "products" created by various combinations of resource conditions; they are analogous to the "goods and services" provided in an industrial situation. Examples of resource outputs include various forms of fish habitat, wildlife habitat, recreation opportunities, irrigation, and hydropower production. It is useful to further divide resoruce outputs into **instream resource outputs** and **out-of-stream resource outputs.** In the former, outputs are produced by maintaining or providing instream flow; in the latter, outputs are produced by taking water out of the river.

Stops refer to times when a canoe or raft is "hung up" on a rock or gravel bar. It differs from a hit in that the boat's forward momentum is lost. In order to get "unstopped," boaters must push off the obstacle with a paddle, an oar, or a foot. Shifting weight in the boat (having a passenger move from one side of the raft to another) may also be required. Stops are relatively unobtrusive floatability problems, unless they happen frequently.

Swimmability refers to the combination of conditions that create good swimming opportunities. Depending on the river and type of swimming in question, swimmability may be associated with the depth of pools, the velocity of the current, the river aesthetics, or the availability of beaches or rocks for sunbathing.

Wadeability refers to the ability of recreationists to stand in a river (usually to fish). Wadeability is often an important element in determining overall fishability. Wadeability is related to combinations of current velocity and depth given a certain type of channel bottom (gravel is easier to stand on than rounded boulders, etc.).

Whitewater challenge refers to the level of "thrill, skill, and fun" associated with running whitewater. For flow - recreation studies, the issue is how challenge changes at different flow levels. Challenge is half of the whitewater equation; safety is the other half.

Whitewater safety refers to the level of risk to people and equipment associated with running whitewater. With flow - recreation studies, the issue is determining whitewater safety risks at different flow levels.

As the Nation's principal conservation agency, the Department of Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people. The department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

Publication services were provided by the National Park Service, Rivers and Trails Conservation Program and the National Park Service, Pacific Northwest Region, Cooperative Park Studies Unit at Oregon State University. The Rivers, Trails, and Conservation Program provides assistance to federal, state, and local governments or other organizations to protect rivers, develop trails, conserve the character of the landscape, and help groups achieve their conservation goals. The program draws its authority from three Acts of Congress: the Outdoor Recreation Act of 1962, the Wild and Scenic Rivers Act of 1968, and the National Trails Systems Act of 1968. All three call for the protection of resources for future generations. The products of the Rivers, Trails, and Conservation Program, measured in resources protected and recreation opportunities provided, ensure that future generations of Americans will continue to recreate and find renewal in the out-of-doors.