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ASSESSING THE DIRECT EFFECTS OF STREAMFLOW ON RECREATION: A LITERATURE REVIEW[1]

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ABSTRACT: A variety of methods have been used to learn about the relation between streamflow and recreation quality. Regardless of method, nearly all studies found a similar nonlinear relation of recreation to flow, with quality increasing with flow to a point, and then decreasing for further increases in flow. Points of minimum, optimum, and maximum flow differ across rivers and activities. Knowledge of the effects of streamflow on recreation, for the variety of relevant activities and skill levels, is an important ingredient in the determination of wise streamflow policies.
(KEY TERMS: instream flow; user survey; valuation.)

INTRODUCTION

River and stream corridors provide a variety of valuable natural resources, including aquatic habitat for fish and other organisms and riparian habitat for terrestrial wildlife. Stream courses also provide "recreation habitat" for a variety of human activities. The quality and value of many of these resources and activities are related to streamflow, either directly or indirectly.

Population growth and economic growth have gradually increased demands for diversions from streams; yet, this very growth has also included demand for stream-based recreation. The same forces have increased pressures for alterations in flow patterns to enhance hydroelectric production, alterations that often conflict with stream-based recreation. In response to these conflicts, several laws, such as the Wild and Scenic Rivers Act, the Federal Power Act, and several general land and resource management acts, have encouraged competent tradeoff evaluation (see Shelby *et al.*, 1992a, for more on federal and state legislation). To adequately assess the tradeoffs between recreation and other water uses, we need to improve our understanding of the relation of flow to recreation quality and value, employing the best methods available.

Assessments of the relation of streamflow to recreation have been carried out in a variety of settings, for a variety of purposes, and from a variety of disciplinary perspectives. Studies have focused on determining minimally acceptable flows, or on the relation of flow to recreation over the full range of flows. Studies have focused on recreation quality, economic value, aesthetics, carrying capacities, and interactions of recreation streamflow needs with other water needs. Studies have focused on water-dependent activities, such as boating (using numerous craft, including rafts, canoes, drift boats, and kayaks), fishing, and swimming, and on water-enhanced activities, such as camping, picnicking, and hiking. Some of these studies are described herein.

A fundamental distinction can be drawn between the study of (1) direct or short-term effects of flows on recreation in general or on specific recreation attributes, such as quality of rapids, fishing success, scenic beauty, or boating travel times; and (2) indirect or longer-term effects, such as the maintenance of gravel bars for camping, control of encroaching vegetation to ensure scenic visibility, or the maintenance of channel form and function for fish habitat. Most direct-effects studies have focused on expert or general user evaluations of recreation quality or value, although some (those using acoustical equipment to measure sound level) are purely descriptive. The studies of indirect or longer term effects are all purely descriptive of physical effects. In the following discussion, we will focus primarily on the direct effects of flow on recreation.

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Another fundamental distinction can be drawn between those studies that measure the effect of flows on recreation in a specific river or stream, and those studies that specify a model of the relationship between recreation and instream flow that can be applied on numerous rivers and streams. We will categorize and compare methods employed in site-specific studies, and discuss the use of multi-river models.

In our review of over 25 instream flow studies, we consistently found that recreation quality increased with flow to a point, and then decreased with further increases in flow. For any given river reach, the points of minimum, optimum, and maximum flow usually differ by activity and skill level, although there is often significant overlap in ranges of desired flows across activities. We will conclude this paper with some observations about this finding and some suggestions for future research.

DIRECT MEASUREMENT OF SITE-SPECIFIC STREAMFLOW EFFECTS ON RECREATION

Methods used to evaluate the direct effects of streamflow on recreation quality can be grouped into four categories. The first approach is to rely mainly on the judgment of experts who have past experience on the study river or other rivers. The expert's judgment is perhaps supplemented by onsite investigation in the course of the study, or by informal interviewing of a limited number of selected individuals. However, with this approach, there is no systematic onsite or photo-based evaluation of alternative flow conditions at the time of the study, or any concerted attempt to survey the user population. The second approach uses systematic assessment of alternative flow levels by a small sample of judges, where each judge evaluates each flow level over the course of a relatively short time. Of particular importance here is the use of a range of controlled flows provided for assessment by planned dam releases. The third approach is to employ a formal survey of a sample of the user population. The fourth approach uses mechanical measurement, with little or no judgment reflected in the dependent variable.

Use of formal surveys to obtain user judgments can be further subdivided into five categories. Four of the categories are distinguished based on whether user responses are obtained (1) for experienced flow where each respondent experiences only one flow level, (2) for alternative flow levels depicted photographically, (3) for alternative flow levels described verbally, or (4) for alternative impacts of flow levels (e.g., catch rates). With the fifth approach, (5) visitor use levels are observed at alternative flow levels.

Table 1 summarizes the methods used to understand direct effects of flow on recreation quality and value and lists some studies that have used these methods. Studies that used more than one method are categorized in the table according to the dominant method used. We briefly describe a few of these studies here to illustrate the approaches. More detail on many of the studies is provided by Shelby *et al.* (1992a).

Reliance on the Judgment of Experienced Individuals

Reliance on expert judgment is a common and relatively inexpensive procedure, but study results are seldom published and circulated for outside review. The following two studies are representative of this approach. (1) Beaver Creek, a tributary of the Yukon River in Alaska, receives so little recreational use that a formal user survey was infeasible. In order to develop recommendations of minimum flows needed to maintain a quality canoeing experience and meet other objectives in the designated national wild river portion of Beaver Creek, Van Haveren *et al.* (1987), relied largely on their expert judgment, in light of data they obtained during a site visit, a literature review, and selected interviews with a few knowledgeable managers and users. (2) The Cache La Poudre River in Colorado receives ample recreation use, but study limitations precluded doing a user survey to specify the relationship of recreation quality to flow. Rather, Williams (1991) relied on a few experienced local users and managers. For each of six activities (rafting, kayaking, canoeing, tubing, fishing, and wading) six to ten people specified, in a Delphi process, the minimum and maximum flow levels, and the optimum flow range, on relevant stretches of the river.

Systematic Assessment by a Small Sample

For systematic assessment of alternative flow levels, the conditions to be evaluated may be represented photographically or actually experienced. Photos are particularly useful when it would be otherwise impossible to visit and experience the various flow levels within a sufficiently short time-span that the judges' evaluation criteria did not change. In either case, the same individuals judge each flow level for whatever activities are at issue, and record their impressions and evaluations in either a formal questionnaire or a monitored group discussion.

TABLE 1. Direct Effects Methods and Some Studies That Have Applied Them.

Method	Study: Author (date)	River (state)	Activity*	Dependent Variable
DIRECT MEASURES OF SITE-SPECIFIC EFFECTS				
Expert Judgment	Van Haveren *et al.* (1987)	Beaver Creek (AK)	Canoeing	Floatability
	Williams (1991)	Poudre (CO)	Several	Rec. Quality
Systematic Assessment of Flows, Small Sample				
Flows Depicted by Photos	EA Engineering (1990)	Clavey (CA)	Swimming	Suitability
	Litton (1984)	Toulumne (CA)	Viewing	Visual Quality
Controlled Flows Experienced Onsite	Bayha and Koski (1974)	Snake (ID)	Several	Several
	EA Engineering (1991)	McKenzie (OR)	Boating	Suitability
	Giffin and Parkin (1991)	Kennebec (ME)	Rafting, Fishing	Rec. Quality, Safety
User Surveys				
One Experienced Flow Per Respondent	Bishop *et al.* (1987)	Colorado (AZ)	Rafting, Fishing	WTP/Trip
	Duffield *et al.* (in press)	Big Hole and Bitterroot (MT)	Fishing, Shoreline	WTP/Day
	Moore *et al.* (1990)	Aravaipa (AZ)	Hike, Swim	Preferred Flow
	Shelby *et al.* (1990)	Gulkana (AK)	Boating	Rec. Quality
Flows Depicted by Photos	Brown and Daniel (1991)	Poudre (CO)	Viewing	Scenic Beauty
	Daubert and Young (1981)	Poudre (CO)	Fish, Boat, Shore	WTP/Day
	Ward (1987)	Chama (NM)	Fishing, Boating	WTP/Season
Flows Described Verbally	Bishop *et al.* (1987)	Colorado (AZ)	Rafting, Fishing	WTP/Trip
	Narayanan (1986)	Blacksmith Fork (UT)	Camp, Hike, Fish	Visits/Year
	Shelby *et al.* (1992b)	Colorado (AZ)	Rafting	Quality, Safety
	Vandas *et al.* (1990)	Dolores (CO)	Boating	Rec. Quality
	Walsh *et al.* (1980)	Several (CO)	Fishing, Boating	WTP/Mile/Day
Flow Impacts Described Verbally	Harpman (1990)	Taylor (CO)	Fishing	WTP/Year
	Johnson and Adams (1988)	John Day (OR)	Fishing	WTP/Year
Observation of Use at Various Flows	Several	Several	Several	Visitors/Day
Mechanical Measurement	Garn (1986)	Red (NM)	Listening	Decibels
	Hawkins (1975)	Several (UT)	Listening	Decibels
MODELS				
Conceptual	Milhous (1990)	Salmon (NY)	Several	Suitability
	Nestler *et al.* (1986)	Chattahoochee (GA)	Several	Rec. Quality
Empirical	Corbett (1990)	45 Rivers	Canoeing	Minimum Flow

*Shoreline indicates picnicking, camping, hiking, and relaxing.

The photographic approach was used in two California studies. (1) Scenic quality along the Toulumne River was assessed by Litton (1984). He reviewed photographs taken at various flow levels from several photo points along the river and used his training as a landscape architect to describe the effects of flow on visual quality. (2) Swimming suitability along the Clavey River near its confluence with the Toulumne River was assessed by capturing alternative flows on video tape (EA Engineering, Science, and Technology, 1990). During the summer of 1988, as flow levels became available, members of the study team were photographed as they swam in ten different pools at eight flow levels ranging from 8 to 385 cfs. The videos were later shown to a panel of six judges who rated the conditions for swimming suitability.

Upstream dams offer a unique opportunity to provide a range of actual flow levels over a relatively short period. Where dam operators have cooperated, the controlled-flows approach has clearly contributed to understanding flow-recreation interactions. Two studies used this approach in 1973. (1) The Tennessee Valley Authority (TVA) arranged for about 30 canoers, kayakers, and rafters to float a stretch of the Ocoee River in Tennessee at three controlled flows ranging from 1,200 to 4,000 cfs (personal communication, George Humphrey, TVA, 1990). The participants, largely local boating enthusiasts, floated the three flow levels over the course of two days and discussed the relative merits of the flows as a group. (2) A multi-agency study team evaluated flows on the Hells Canyon section of the Snake River (Bayha and Koski, 1974), experiencing several flow levels ranging from 5,000 to 27,000 cfs from Hells Canyon Dam over a five-day period. Participants were representatives from a variety of disciplines (e.g., hydrology, fisheries, recreation) who carefully monitored and recorded the recreation impacts.

More recently, controlled flows were used along the McKenzie River in Oregon to study boating suitability (EA Engineering, Science, and Technology, 1991). Three flow levels were floated on separate day-long trips organized for the same week. Ten selected individuals, ranging from novice to expert, participated in each trip, floating the river in a drift boat, canoe, raft, or kayak. Each of 11 sections of the river was evaluated by each participant using a standardized response form, with no discussion among panel members regarding their evaluations.

In another recent field evaluation, Central Maine Power Corporation provided a range of flows on two separate one-day occasions in the summer of 1990 in the 3½-mile-long East Outlet of Moosehead Lake, at the headwaters of the Kennebec River in western Maine (Giffen and Parkin, 1991). For the boating assessment, on each occasion, six different flow levels were provided, ranging roughly from 900 cfs to 5,500 cfs. The different flow levels were floated by about 15 people in rafts, kayaks, and canoes. Participants were encouraged to take detailed notes about each flow level. On the first occasion, boating participants discussed each float trip as a group, while on the second, group discussion was discouraged and participants provided independent written evaluations of the alternative flow levels. In addition, key points of the stretch were videotaped at each level as participants floated by for later review by the study team. For the fishing assessment, which occurred only once, six flow levels from 600 to 1,600 were fished by two anglers in different locations. Anglers' comments were recorded onsite by accompanying members of the study team.

Studies Employing User Surveys

The bulk of the studies published in the journal literature of the effects of flows on recreation have relied on user surveys, usually employing an onsite interview or mail questionnaire. These studies are categorized here into five subclasses based on whether they used photographic media, verbal descriptions, or actual flows to represent the conditions of interest, on whether flow levels or impacts of flows (e.g., catch rate) were described to respondents, and on whether users responded to a questionnaire or were merely observed.

While most of these studies focused directly on recreation or scenic quality, several measured the economic value of riverine recreation (see Loomis, 1987, for a description of several studies of the economic value of instream flow). The economic value of such recreation can be influenced by both the changing recreation quality at alternative flow levels and the changing number of users. It is the economic measure of the quality effect, not of the use or quantity effect, that is most closely related to the measure obtained in studies focusing directly on recreation quality. If an estimated relation of economic value to flow is primarily or wholly influenced by the quality effect, that relation can confidently be compared with direct recreation quality measures.

One user survey approach is to record the actual flow experienced by users during the trip about which they are questioned, and then statistically relate user responses to measured flows. This requires a much larger sample of users than does field evaluation where each participant experiences all levels over a short period, but still has the advantage of being tied directly to onsite experience. This approach was used by Moore *et al.* (1990), in a mail survey of recent visitors to Aravaipa Canyon Wilderness in Arizona.

Visitors were asked whether they preferred the flow volume they encountered or would have preferred higher or lower flows. These responses were compared with gauged flow at the time of the visit to understand visitor preferences. A pair of contingent valuation studies used this approach. Duffield *et al.* (in press) used an onsite survey on two Montana rivers to estimate users' additional willingness to pay for their current recreational experience. And Bishop *et al.* (1987) surveyed Colorado River recreationists (Grand Canyon rafters and Glen Canyon anglers) by mail about their additional willingness to pay for their recent trips. In both studies, responses were statistically related to flows experienced during the trips.

Photos allow a full range of environmental conditions to be shown to a respondent at the same time. Photos have been used extensively in public surveys to assess the scenic beauty of forests (Ribe, 1989) and other environments, and they have been found in many studies to faithfully depict the attributes of actual scenes (Shuttleworth, 1980). Daubert and Young (1981) used contingent valuation to estimate willingness to pay of floaters, anglers, and shoreline users on the Cache La Poudre River in Colorado. Onsite respondents were shown photographs that depicted flows of eight levels ranging from 50 to 1,150 cfs. Brown and Daniel (1991) investigated the relation of flow to perception of scenic beauty on the same river. Because flow movement and sound may play a role in the aesthetic quality of river scenes, they used video sequences to represent the flow levels. Observers rated the scenic beauty of video sequences, which showed eight flow levels ranging from 120 to 2,650 cfs. The ratings were scaled to an interval-scale metric of scenic beauty that was regressed on variables describing flow and other scene features.

Several studies have used verbal descriptions of flows to represent alternative conditions to respondents. For example, an economic study surveyed users of nine rivers on the West Slope of the Colorado Rockies (Walsh *et al.*, 1980). Respondents were asked their willingness to pay for recreation given current conditions, and then for the changes in that willingness to pay at five different instream flow levels described as percentages of bankfull flow. And in the Colorado River contingent valuation study by Bishop *et al.* (1987), cited above, after valuing their actual trips, users were asked their willingness to pay for six scenarios that differed in both amount and daily fluctuation of flow, and in associated conditions of rapids and camping beaches. In two noneconomic studies, river users of the Dolores River in southwestern Colorado (Vandas *et al.*, 1990) and river guides of the Colorado River through the Grand Canyon (Shelby *et al.*, 1992b) were questioned about boating quality at alternative flow levels. (The latter study is actually a hybrid – a formal survey of experts, with a substantial sample size.)

Rather than describe alternative flow levels to study participants, some studies have described flow-dependent recreation attributes. For example, two economic studies (Johnson and Adams, 1988; Harpman, 1990) asked respondents to express their willingness to pay for alternative catch rates. Resultant recreation values for catch rates were related to flow using flow-dependent fish production models.

A careful survey of use of a river reach as flows change over the season can also provide a measure of the popularity of alternative flows. However, this method is difficult to apply because use is sensitive to many influences in addition to flow levels, and because users often do not know what flow level to expect when they make a trip. Even assuming flows are known ahead of time, all the other influences must be controlled to isolate the impact of flow. While use levels have been measured in conjunction with several studies cited herein, investigators have generally used it as a check on other methods rather than as the primary method for assessing recreation quality.

Mechanical Measurement of Descriptive Effects

Two studies of sound, an aesthetic feature of rivers, used a decibel meter to provide a purely descriptive measure. Hawkins (1975) measured noise level and flow rate at several streams in Utah, and Garn (1986) adapted this methodology to measure sound output at various flow levels at a river stretch in New Mexico. The nonlinear relationships they found indicated the point at which additional flow contributed little to sound output.

MODELS OF RECREATIONAL-FLOW RELATIONS

Almost all of the studies mentioned above and listed in Table 1 are river-specific studies, rather than studies that attempt to develop a multi-river model. Such models of the flow-recreation relation have considerable appeal, especially if they rely on generally available hydrologic data. A model is particularly useful when a site-specific study of the relation of flow to recreation quality is too expensive or too time-consuming, where key flows cannot be observed (e.g., where recreation assessments are being made for a flow-regulating facility that does not exist), or where the user population is difficult to identify (e.g., on remote Alaskan rivers).

Two distinct modeling approaches were found in the literature. (1) The conceptual approach specifies *a priori* functional relationships of physical variables to recreation quality or potential quantity of recreation use, and relies on detailed onsite assessment procedures and subsequent computations. (2) The empirical approach utilizes data collected at many rivers to estimate a statistical relation between one or more flow variables and some recreation quality variable. The resultant empirical model could then be applied to other rivers of a similar character.

Conceptual Model

Perhaps the best known conceptual modeling approach for assessing streamflow-recreation relations was developed by Hyra (1978) based on methods used to evaluate fish habitat. Hyra actually proposed two methods, the "single cross section method" for determining minimum acceptable flows from measurements taken at a carefully located transect, and the "incremental method" using multiple transects to more completely assess the recreation potential of a stream reach. Hyra's incremental method is of most interest here. It translates depth and velocity (from the transects) and surface area, for selected stretches of the study reach, into an overall assessment of usable recreation "potential" for a given activity. Measured depth and velocity are each translated into indices of recreation suitability based on what Hyra (1978) called "probability of use" curves. These curves essentially express the suitability for a given type of recreation at different water depths and at different flow velocities, on a scale from 0 to 1, where 0 indicates the high or low depths or velocities at which the activity ceases to be possible, and 1 indicates optimal depth or velocity for the activity. The suitability indices for depth and velocity are multiplied, and the product is then multiplied by the associated surface area to compute a "weighted useable surface area for the given activity," indicating recreation potential. The essential qualitative ingredients of this process are the suitability curves. Studies using Hyra's incremental method, such as Nestler *et al.* (1986) on the Chattahoochee River in Georgia and Milhous (1990) on the Salmon River in New York, used expert judgment to delineate these curves, but they could conceivably be estimated by a user survey or other means.

Empirical Model

Corbett's (1990) recent modeling effort is the first attempt we now of to develop a multi-river empirical model relating recreation to flows. Corbett developed a statistical relation of minimum canoeing flow to mean annual flow based on data from 45 rivers. The dependent variable, "canoeing zero" flow, was defined as 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 reference to canoeing guide books. Regression of canoeing zero flow on mean annual flow produced an equation that appears, in graphic presentation, to accurately specify the relation between these two variables (statistical measures of association were not reported). This equation shows canoeing zero increasing at a decreasing rate relative to mean annual flow (for every doubling of mean annual flow, canoeing zero flow increases by about 50 percent). More recent work by Corbett (presented at the "Instream Flows and Recreation" workshop at Oregon State University in March 1991) indicates that some of the dispersion in his two-dimensional model can be accounted for by distinguishing between white water and calm water rivers (i.e., accounting for bottom roughness, with rougher bottoms requiring more water) and standardizing the location of flow measurement to a common point (e.g., the beginning) of each relevant stream reach.

COMPARISON OF METHODS

Much has been written about the merits of alternative evaluation methodologies (e.g., Loomis, 1987; Jackson *et al.*, 1989; Shelby *et al.*, 1992a). We will not repeat this advice. However, perhaps a short comparison will help those contemplating an assessment of streamflow impacts to choose the most appropriate methods.

Reliance on the judgment of a small sample of experts has the advantage that it can be quickly and easily applied, efficiently focusing most study effort on those judges most likely to understand the relevant issues and relationships. This method is particularly useful where there are few users to interview (perhaps because of remoteness) and where direct observation of various contemplated flow levels is not possible. The principal drawback of relying on a small sample of experts is the potential for bias and the resultant ease with which important considerations may be overlooked or distorted.

Systematic experience-based evaluation of alternative flow levels over a short time span is an efficient and powerful approach. Except for potential order effects, it places all important flow levels on an equal footing. Furthermore, experiencing the flows affords the possibility that impacts otherwise ignored or considered unimportant can surface in the course of the study. Controlled flows are superior to photographic representations for complex activities such as boating and fishing, but carefully obtained photos may adequately represent the scenes for assessment of scenic quality alone.

In some applications of this approach, there has been a tendency to restrict the sample to a small number of study members rather than opening the evaluation up to a larger number of participants. In addition to potentially enhancing the validity of study results, inviting wider participation is a good way to enhance public knowledge and acceptance of a study. In any case, careful consideration of the response mode is needed; group discussions, while easy to arrange, are probably less effective than comments recorded separately by each participant in response to a specially prepared questionnaire. Group discussions may provide useful additional information, but should occur after the questionnaires are completed.

User surveys employing statistically relevant samples, if properly designed, have the advantage of avoiding biases that may be unavoidable among small groups of experts or participants in an assessment of controlled flows, and user surveys allow the estimation of economic value. However, user surveys are complex, requiring competent questionnaire design and sampling procedures.

Users, of course, differ in their experience with alternative flow levels. More experienced users are more likely to provide survey responses from which a significant relation of flow to recreation quality can be delineated, if one exists. More experienced users are also more likely to be able to go beyond just the overall effect of flows on recreation quality to provide useful information about the effect of flow on specific rapids, camping sites, safety concerns, and other aspects of the recreation experience (see, for example, Shelby *et al.*, 1992b).

Measures of the effect of flow on recreation quality alone do not indicate how important those effects are. A significant, carefully delineated change in recreation quality may or may not be worth much to users. The importance of a change is commonly measured with an economic study. As mentioned above, two approaches to measuring the economic value of instream flow are to ask each respondent about a series of verbally or photographically depicted flow levels, and to ask each respondent about only one experienced level. The former approach tends to focus respondents' attention on comparison of the alternative flow levels. If recreation quality is at all sensitive to flow, this multiple-flow, comparative approach is more likely to yield results indicating a responsiveness of economic value to flow. In contrast, the method where each respondent is asked about a recent trip (and the experienced flow is later statistically compared to respondents' judgments) does not tend to emphasize flow differences, and allows other important factors (e.g., weather and crowding) to play a larger role in the response. If a significant relation is found between flow and recreation value, when each response refers to an actual trip and the respondent is not aware that flow level is the key variable of interest, the result can be considered particularly robust.

Of course, both methods can be used. For example, Bishop *et al.* (1987) first asked respondents to value their actual trip, and then asked them to value scenarios describing alternative flow levels. The more involved scenarios allowed detailed evaluations, which carried more weight in decision making because the respondents had previously indicated that the value of their actual trips was related to flow.

Methods of assessing the relation of recreation to flow can also be distinguished in terms of whether the assessment focuses on flow itself, on the impacts of flow, or on the components of flow. Most studies have focused directly on flow, asking participants to judge (in terms of suitability, willingness to pay, and so forth) alternative flow levels actually experienced or depicted verbally or photographically. Some studies have taken a related approach, asking respondents to judge the desirability of flow impacts (such as catch rate), which the study authors link to flows via physical models. In contrast, Hyra's (1978) approach breaks flow into its components (originally depth, velocity, and surface area), assesses recreation in terms of these components, and then achieves an overall recreation quality measure via a mathematical combination of the component effects.

A major advantage of Hyra's (1978) recreation model, that it is comparable with the results produced by the fish habitat assessment procedure PHABSIM (Bovee, 1982), is also the source of some shortcomings. First, depth and velocity may not be the best flow variables for predicting recreation quality. Experienced river recreation users are more accustomed to thinking of flow in terms of cubic feet per second or stage readings from a gauge. Translating flow into depths and velocities may be both unnecessary and confusing if users are asked to help calibrate suitability curves for depth and velocity of different flows. Second, hydraulic modeling of flow based on selected transects will often inadequately describe the complex nature of water movement in rapids. Transects originally selected for determining fish habitat, especially, may ignore features that are particularly relevant for boating. [Milhous (1990) included a "Froude number" measure of turbulence to try to capture the role of rapids for boating.] Third, the complex procedure of considering flows in terms of flow components may restrict the researcher to relying on personal judgment, or on the judgment of a small number of "experts" who are able to translate flow into depth and velocity, running the risk of relying on biased evaluative judgments. Finally, "weighted useable area" of water surface may be an unnecessarily complex way to express recreation potential in relation to flows, which may obscure the dependent variable, recreation quality. While Hyra's approach is notable for addressing the spatial element of recreation potential, for some activities, such as boating, an area measurement may not be as relevant as a simple measure of length or travel time.

Efforts have been undertaken to incorporate width of the river reach and geomorphic class (boulder, braided, or meander zone) as parameters for Hyra's approach (Scott and Hyra, 1977). Some such parameters are critical for calculating suitability for different types of recreation, especially whitewater rafting, canoeing, and kayaking. Other parameters currently under consideration include turbulence and potential "stranding of fishermen" (Milhous, 1990). However, the question remains – Is the PHABSIM framework the best one for addressing all flow-based recreation questions? The advantage of using this framework – that it is also used to assess fish habitat, thus offering comparability with habitat assessment – is perhaps outweighed for nonfishing recreation by the cumbersome and potentially inefficacious requirements to express recreation quality in terms of a preselected set of site components.

Corbett's (1990) multi-river modeling effort has demonstrated the potential of empirical models. However, 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. Minimum flows for other craft differ from those for canoeing, optimum as well as minimum flows are of interest, and mean annual flow is not the only relevant independent variable (see Shelby and Jackson's 1991 review of Corbett's paper). But Corbett's modeling approach, the development of a multiple-river, empirical, instream flow-recreation model, is an important new direction in instream flow recreation assessment.

SUMMARY AND CONCLUSIONS

Legislation passed in the last 25 years at the state and national levels has recognized the importance of maintaining instream flow in our rivers. In response, numerous investigators, especially in the last five years, have studied the relationship of streamflow to recreation quality. Some studies measured economic value of recreation, while others focused directly on recreation quality; some studies focused on the direct impact of flow on recreation, while others emphasized indirect impacts; and some researchers focused on minimum flows, while others emphasized the full range of flows. These efforts have added considerably to our knowledge.

Four principal approaches to understanding the effect of flows on recreation are reliance on expert judgment (perhaps supported by onsite reconnaissance), systematic experience of alternative flow levels by a small sample, user surveys of various types, and modeling of river-recreation interactions. (1) Expert judgment is efficient and probably the most commonly used approach. (2) Systematic assessment by a small sample is a powerful and flexible approach. One particularly promising method in this regard, systematic assessment of dam-controlled flows, will probably be used much more in the near future, especially in conjunction with FERC relicensing deliberations. (3) User surveys, while complex, can avoid small sample biases potentially associated with other approaches. Such surveys also offer the option of expressing user input in terms of economic value or direct recreation quality measures, and allow examination of unexperienced scenarios. (4) Models, if properly developed and carefully applied, offer a relatively inexpensive approach to predicting recreation flow needs. Models are especially useful for predicting flow impacts for conditions that do not yet exist on the subject river. If a multi-river model is used to assess conditions for existing flows, it is wise to field check the model results. The effects of flows on recreation can usually be more effectively assessed by actually experiencing the river at various flow levels, or by interviewing people who have experience doing so, than by replying on a model.

The Inverted-U Relation

A few studies of the direct effects of flow on recreation quality have focused on minimum flows, but most have investigated the full relation of recreation quality to flow. Perhaps the most robust finding among the many "full relation" studies reviewed was the inverted-U relation of recreation quality to flow.

Flows below a certain level are unusable. Above that minimum, recreation quality rises with flow, levels off at some intermediate range, and then drops as flow continues to rise. Flows above some point, for most rivers, are unsafe or simply unusable. The few studies that did not find the inverted-U relation showed recreation quality continually rising with increasing flow (such as Daubert and Young's (1981) findings for rafting), but, in all those cases, it is apparent that the highest flow level studied was simply not large enough to capture the downturn. The points of minimum, optimum, and maximum flows differ with channel size and configuration, with activity, and with skill level. It is notable that the relation was found not only for boating and fishing, but also for riparian hiking (Moore *et al.*, 1990) and scenic beauty (Brown and Daniel, 1991).

It is also notable that the relation was found across a wide range of methodologies. The inverted-U relation was found not only among studies that emphasized comparative judgments, but also in studies where each user only responded about an actual trip and the responses were statistically related to flow levels experienced at the time of those trips. Such an approach detected significant inverted-U relations for both recreation quality (Moore *et al.*, 1990; Shelby *et al.*, 1990) and willingness to pay for the recreation experience (Bishop *et al.*, 1987; Duffield *et al.*, in press).

Minimum Flow or Flow Relations?

Because instream flows have often been protected or administered as minimum flows, there is a tendency to think of flow needs for recreation in terms of a single minimum value. A more complete picture is gained by describing the entire flow-quality relation. Such a relation shows how recreation quality is affected by the full range of flows, highlights the differences between activities, and clarifies the difference between unacceptable, minimum, and optimum flows. Although some will still request flows by specifying a single amount for any specific period, it is most informative to express requested flows in terms of the levels of recreation quality desired.

Variety and River Recreation

In reviewing studies that have addressed the relation of streamflow quantity to recreation quality, the importance of variety or diversity gradually became obvious. There is a wide variety of recreation activities possible along rivers, including fishing, swimming, boating, hiking, camping, and viewing. Boating is, in fact, a whole group of craft-specific activities – boating includes rafts (rowed, paddled, motorized), canoes (open or closed, and of various shapes and sizes), kayaks (hard shell or inflated), power boats (jet boats or propeller craft), river boats (drift boats and dories), and craft specifically designed for fishing. Each of these activities may utilize different, though sometimes overlapping, ranges of flows. Conditions for some of the activities can be provided concurrently, while others can only be accommodated in series. And there is a wide variety of skill levels among anglers, swimmers, and users of the different craft, such that different people participating in the same activity are interested in utilizing different flow levels. The variety of potential activities and users creates a complex mixture of management options that is difficult to assess without considerable knowledge about the unique resource and user conditions along a given river reach.

Another aspect of variety, which is rarely mentioned in the literature, is the variety in flow over the recreation season for a given activity. As mentioned above, studies consistently showed that there is an optimum range of flows for any given activity. One naturally concludes from this that infrequent users would prefer to encounter flows in the optimum range. However, what about the frequent user? Perhaps a variety of flow levels, including levels both below and above the optimum range, would be preferred by the repeat visitor. Recreation quality over the season or over years of returning to the same stretch or river may actually be enhanced if flows are sometimes outside the optimum range. Of course, variety in flow is the natural norm for most rivers. Likewise, a manager's effort to provide optimum flows for a mix of flow-dependent activities naturally leads to a variety of flow levels. The importance of variety, and options for offering it, should receive more attention in future instream recreation studies.

Future Directions in Streamflow-Recreation Research

Empirical multiple river modeling is a promising direction for instream flow recreation assessment. Development of multi-river empirical models, of course, requires that comparable data are collected for each river. Individual river studies could contribute to such multi-river data bases if sufficient data were collected during the individual efforts. A critical need in this regard is some agreement on the variables that should be routinely measured. For example, one obvious improvement would be to report flow in terms of percent of bank-full flow, in addition to discharge. Some agreement on a standard set of variables would facilitate comparison of individual study results, even if multi-river modeling were not attempted.

Future efforts should also consider systems of stream channel classification as sources of independent variables. For example, Rosgen's (1985) stream classification system uses measures of stream gradient, sinuosity, width and depth, dominate particle size, channel entrenchment, and landforms to distinguish among stream types. Perhaps such variables would facilitate comparisons across rivers and enhance empirical modeling efforts.

Understanding of instream flow-recreation relationships may also benefit from adaptation of tools and concepts developed in the field of outdoor recreation research. For example, the Recreation Opportunity Spectrum (Driver and Brown, 1978) approach might be adapted to instream recreation. This would have two advantages. First, it would more clearly focus research on the quality of the recreation experience and on the benefits obtained from instream recreation. Second, it would make river-dependent recreation designations compatible with larger, land-based planning systems of recreation and other natural resource use.

Future work should investigate the importance to recreation of variety in flows and the related impacts of flow timing. Future work should also emphasize empirical models of flow effects, models that address the full relation of flow to recreation quality and that can incorporate a sufficient number of independent variables such that the models can be applied across a range of rivers.

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