GRAND CANYON RECREATION AND GLEN CANYON DAM OPERATIONS: AN ECONOMIC EVALUATION*

BY

RICHARD C. BISHOP
PROFESSOR
DEPARTMENT OF AGRICULTURAL ECONOMICS
AND CENTER FOR RESOURCE POLICY STUDIES
UNIVERSITY OF WISCONSIN -- MADISON

CURTIS A. BROWN
CHIEF
DECISION ANALYSIS SECTION
U.S. BUREAU OF RECLAMATION
DENVER, COLORADO

MICHAEL P. WELSH
SENIOR PROJECT MANAGER
HBRS, INC.
MADISON, WISCONSIN

AND

KEVIN J. BOYLE
ASSISTANT PROFESSOR
DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS
UNIVERSITY OF MAINE
ORONO, MAINE

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INTRODUCTION

The research reported here focused on the effects of Glen Canyon Dam operations on the quality of recreation downstream. Glen Canyon Dam is located on the Colorado River in Arizona, just south of the Arizona-Utah border. The Colorado River below the dam is located in Glen Canyon National Recreation Area. Further downstream, the river enters Grand Canyon National Park. Two types of recreation were studied in detail, fishing and white-water boating.[1] From a recreational perspective, different discharges from the dam affect the conditions under which downstream fishing and white-water boating occur. Flows in the river could be a significant determinant of recreational quality.

The study was conducted as part of the Glen Canyon Environmental Studies (GCES), a multi-agency effort to examine the impacts of dam operations on the environmental and recreational resources downstream. The mission of the initial phase of GCES was to determine whether operations were adversely affecting downstream environmental and recreational resources and, if so, whether ways could be found, within existing institutional constraints, to improve or better protect environmental and recreational resources.[2] The overall goal of GCES -- and hence the work on recreation reported here -- was

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[1]Fishing and white-water boating were the only forms of recreation we were able to identify where dam operations are having a significant effect. As part of the study we also examined day-long raft tours on the 15-mile stretch of the river just below the dam. However, no significant effects of dam operations were identified. See Bishop, et al. (1987). While Grand Canyon National Park attracts millions of visitors, the vast majority are not affected by dam operations.

[2]Results relating to recreational aspects other than quality, including recreational accident rates, as well as other environmental concerns associated with dam operations, are summarized in a report by the U.S. Bureau of Reclamation (1988).

not to prescribe specific actions to be taken, since this would have involved much broader trade-offs between recreation, power generation, environmental effects, and other social objectives. Rather, our goals were the more limited ones of determining the effects of dam operations on recreational quality and developing options that would benefit recreation considered alone. The results reported here will eventually be combined with results from studies on the downstream environment, electric power generation, and other resources in order to construct and evaluate dam management options.

We used dollar measures to quantify recreational impacts. Thus, the study design, as described later in the paper, was built on theoretical links between environmental quality and consumer surplus explored thoroughly by Maler (1974) and Freeman (1979). Using dollar values not only conveys recreational quality impacts in a commonly used metric, but may also eventually facilitate the analysis of trade-offs between recreation and other goals using the tools of benefit-cost analysis.

In the next section, the relationships between dam operations and recreation will be explored. Following this, the design of the study is summarized and the measured consumer surplus values for fishing and boating reported. We then illustrate ways that dam operations could be modified to improve downstream recreation.

RECREATION AND DAM OPERATIONS

As Lake Powell began to fill after completion of the Glen Canyon Dam in 1963, cool water from deep in the reservoir began flowing downstream, creating excellent conditions for trout. By 1980, the 15 miles of river between the dam and Lees Ferry had become one of Arizona's "blue ribbon" trout fisheries, attracting national attention as anglers took many trophy-sized rainbow and other trout in a spectacular setting.[3] Most anglers use boats, launching at Lees Ferry and traveling up the river, but there is also some bank fishing in the Lees Ferry area where the river is accessible by road and short hikes. In 1985, the year used in the analysis presented here, the fishery supported about 15,000 angler-days of recreation.

Over the same period as the trout fishery was evolving, white-water boating along the more than 200 miles of river between Lees Ferry and Lake Mead became increasingly popular. This is one of the premier white-water rafting areas in the world because of the numerous challenging rapids and the magnificent natural setting of Grand Canyon National Park. A wide variety of craft are used, ranging in size from large motor driven rafts to kayaks. Under limits set by the National Park Service, about 115,000 user-days of white-water boating were provided by commercial outfitters in 1985 and in addition, private individuals logged more than 54,000 user-days.

Dam operations determine the amount of water that supports fishing and white-water boating at any point in time. Dam operations are based primarily on criteria relating to water conservation and delivery and power generation. A wide range of releases are needed to fulfill these criteria. Glen Canyon Power Plant, which is located at the dam, has more than 1,300 mega-watts of hydro-electric generating capacity. Under current operating criteria, minimum discharges from the dam are 3,000 cubic feet per second (cfs) in the three summer months and 1,000 cfs during the rest of the year.[4] Full use of all

[3]Some fishing does occur below Lees Ferry, including fishing in the Grand Canyon itself. However, most of the fishing occurs upstream and our study was limited to the segment between the dam and Lees Ferry.

[4]The summer minimum of 3,000 cfs is specifically designed to provide base flows for white-water boating.

eight generators involves releases of up to 31,500 cfs.[5] If tubes that bypass the power plant are also used, total release rates can reach 48,000 cfs. With the reservoir full, spillways can also be used, making total flows of over 100,000 cfs feasible. The maximum actual rate of release since completion of the dam was 92,600 cfs, experienced in 1983.

Within these very broad limits, discharges can vary greatly on an annual, monthly, and daily basis. One reason is that annual inflow to Lake Powell varies widely; historical inflows have ranged from less 9 million acre-feet to over 20 million acre-feet. Over the course of any given year, average monthly dam releases change as water availability and electricity demand change. In a low water year, average discharge rates in some months may fall below 9,000 cfs. In high water years, average flows may exceed 40,000 cfs in the late spring. Flows on any given day are affected by both hydrological conditions and power demand. Within the power system served in part by Glen Canyon Power Plant, the amount of electricity demanded varies greatly during a typical 24-hour period, particularly during the summer and winter months. Hydroelectric power, like that generated at Glen Canyon Dam, can be increased and decreased more easily than power from fossil-fuel plants and nuclear plants to meet daily peaks in the amount of electricity demanded. This is accomplished by increasing and decreasing the flow of water through the turbines as demand increases and decreases. Thus, under normal operations of Glen Canyon Power Plant, it is not unusual for discharges to fluctuate by 10,000 cfs and more each day, particularly during low-water years when water

[5]Actually, as a result of rewinding and uprating the generators during the early 1980's, the generators are capable of handling more than 33,000 cfs, but current operating criteria have maintained the old upper limit of 31,500 cfs pending completion of studies of the environmental and recreational impacts of utilizing the additional capacity.

is scarce and releases are minimized during times of the day when power demand is low. In high-water years, high, relatively stable flows may occur for many days at a time.

STUDY DESIGN

The study assessed the recreational impacts of two characteristics of dam releases: (a) average daily flow; and (b) whether flows were constant or fluctuating on a daily basis. Average daily flows were characterized in terms of the mean release rate at the dam in cfs. Flows were classified as "constant daily flows" if the difference between the minimum and maximum release at the dam during a 24-hour day was less than 10,000 cfs. If this difference was greater than or equal to 10,000 cfs, then the flow on that day was classified as a "fluctuating daily flow." Based on survey research, described below, the 10,000 cfs threshold was determined to be the point at which fluctuations begin to be perceptible to recreationists.

Data relating to recreation came from three main sources: (1) surveys of and informal contacts with guides and private trip leaders; (2) attribute surveys of anglers and white-water boaters; and (3) contingent valuation surveys of the two user groups. Some on-site interviews of anglers were conducted but all other surveying, including other angler surveys, were conducted by mail. Details regarding sampling strategies, survey design and execution, data analysis, and results are reported in Bishop, et al. (1987), and only a brief overview will be possible here.

Commercial white-water guides and private trip leaders were surveyed by mail to better understand their perceptions of how different constant and fluctuating flows affect commercial and private trips and the actions they take to mitigate the adverse effects of flows. The guides described the effects of flows in terms of the need to scout rapids, the need to ask passengers to walk around rapids, the risk of accidents in rapids, time spent on the river each day, changes in the trip itinerary, selection of campsites and mooring locations, minimum and maximum safe flow levels, and the optimal flow levels for trips. Professional fishing guides were contacted informally to gain their insights about the effects of flows on quality.

The responses from attribute surveys of samples from the two user-groups were combined with results from the White-Water Guide Survey and informal discussions with resource managers and fishing guides to identify which important attributes of the fishing and white-water boating experiences are affected by river flows. The flow-sensitive attributes identified for each group are shown in Table 1. This table shows only those attributes that are sensitive to flows. Good weather is an example of an important positive attribute that does not depend on flows and thus is not included in Table 1. As the table demonstrates, many important attributes are flow sensitive.

These results were used to design the contingent valuation surveys. The goal of these surveys was to assess the quality of recreation under different

Table 1. Flow Sensitive Attributes.

Glen Canyon Anglers	Grand Canyon White-Water Boaters
Catching trophy fish	Being in natural setting
Catching fish	Stopping at attraction sites
Access up-river	Running big rapids
Boat problems/damage	Walking around rapids
	Camping beach size and availability

river flows.[6] Recreational quality was measured in terms of consumer surplus, and the effects of dam release patterns on recreational quality were quantified as changes in consumer surplus.

The contingent valuation questions utilized a closed-ended (i.e., dichotomous choice) format, using actual expenses as the payment vehicle. That is, recreationists were asked whether or not they would be willing to pay a specified amount, over and above their actual expenses, for a fishing or white-water boating trip under specified conditions. All that respondents were asked to do was respond "yes" or "no" to the specified, hypothetical increase in expenses. Closed-ended questions are now recognized as a particularly effective and theoretically sound way of conducting contingent valuation exercises (see Bishop and Heberlein, 1979; Hanemann, 1985; Sellar, et al., 1985; Cameron and James, 1987; Boyle and Bishop, 1987, 1988; Bishop, et al., 1988; Bowker and Stoll, 1988 and other literature cited in these papers).

Contingent valuation surveys of both anglers and white-water boaters were conducted by mail. Recreationists were first asked questions designed to estimate the consumer surplus from their actual trips.[7] They were then asked

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[6]The contingent valuation method, as applied in these surveys, involves asking recreationists the maximum amount they would pay, beyond their actual expenses, for access to recreational opportunities. Contingent valuation is being increasingly applied to estimate the values of recreational and other environmental assets. Growing acceptance of the technique is based on an expanding body of research indicating that under certain, increasingly well understood conditions, contingent valuation can provide value estimates that are sufficiently accurate to be useful in policy analysis. For reviews of the literature on contingent valuation and its validity see Mitchell and Carson (1989), Cummings, et al. (1986), and Bishop and Heberlein (1989).

[7]White-water boaters rarely, if ever, take more than one trip per year, and we drew a sample of boaters from National Park Service records of those who took either a commercial or private trip in 1985. The anglers were initially contacted by interviewers at Lees Ferry on selected dates during 1985, and their "actual trip" for purposes of the mail survey they received later was the trip when they were contacted by our interviewer.

to assess how the quality of recreation would change under different dam operating scenarios. Written scenarios were prepared that described the recreation conditions in terms of the flow sensitive attributes and how those attributes would be affected by dam operations. Table 2 illustrates the scenarios by showing one scenario describing fishing at a constant flow of 3,000 cfs and another scenario describing white-water boating at an average daily flow of 22,000 cfs with flows fluctuating from 10,000 cfs to 31,500 cfs.

Scenarios like those in Table 2 were constructed to describe a wide range of flow conditions, as listed in Table 3. For example, the third scenario for the Glen Canyon anglers describes fishing conditions where the average daily flow is 3,000 cfs, but flow levels fluctuate during each 24-hour period between 1,000 and 15,000 cfs. Other special scenarios focusing on potential long-term environmental effects of dam operations were included. For anglers, scenarios were added that described fishing conditions under which the chances of catching a trophy fish were doubled and conditions under which the chances of not catching any fish ("getting skunked") were doubled. For white-water boaters, a special scenario was added describing the recreation experience if substantial numbers of beaches in the Canyon were lost. Potential long-term effects of dam operations of the trout fishery, beaches, and other resources are discussed in the U.S. Department of the Interior document cited in the References (1988). Though interesting, the long-term effects of dam operations are beyond the scope of this paper.

Research is continuing on the extent to which recreationists and others can, based on scenarios, adequately value qualitative changes that they may not have actually experienced. Preliminary evidence, including evidence from the current study, as reported in Bishop, et al. (1987) and Boyle, et al. (1988), is encouraging.

Table 2. Scenarios Describing Two Flow Conditions.

<u>Fishing at a Constant Flow of 3,000 cfs</u>

Boat anglers have said that getting upstream to fish can sometimes be a problem at low water (3,000 cfs or less). At a constant flow of 3,000 cfs, large boats can not get past the sand and gravel bar three miles upstream from Lees Ferry, while even very small boats may have to be dragged over slippery rock gravel bars. Consequently, nearly all of the fishing would occur in the three miles just above Lees Ferry. In addition, damage to boats and motors is somewhat more frequent than at higher water levels. However, low water tends to concentrate fish, and bank anglers can find large areas of exposed gravel and rocks, leaving a great deal of space between the water and the edge of the vegetation.

<u>White-Water Boating with an Average Flow of 22,000 cfs with Fluctuations</u>

With large daily fluctuations from 10,000 cfs to 31,500 cfs, around an average daily flow of 22,000 cfs, most people are aware of water level changes. The boatmen will have to take more care in selecting mooring and camping sites. Due to low water levels in the morning, gear may have to be carried (perhaps across rocky areas) to be loaded on the boats. Boatmen may decide to wait above certain rapids for the water level to rise or may have to hurry to get to a certain rapid before the water level falls. In addition, some rapids may be difficult due to exposed rocks at low water levels and other rapids might be quite large at high water levels, and it is likely that passengers may have to walk around a few of the rapids. When the water is high or rising, however, the standing waves in some of the major rapids become larger, resulting in a bigger "roller coaster" ride.

Responses to the contingent valuation questions were analyzed using statistical methods that have become more or less standard (see Bishop and Heberlein, 1979; Bishop, et al., 1983; Sellar, et al., 1985; Bowker and Stoll, 1988; Boyle and Bishop, 1987, 1988; and Bishop, et al., 1988; for background). Statistical results from the research reported here can be found in Bishop, et al. (1987).

Table 3. Flow Conditions Evaluated by Each Group.

Glen Canyon Anglers	Grand Canyon White-Water Boaters
Actual Trip	Actual Trip
Flow constant at 3,000 cfs	Flow constant at 5,000 cfs
3,000 cfs with fluctuations daily	5,000 cfs with fluctuations daily
Constant 10,000 cfs	Constant 13,000 cfs*
10,000 cfs with fluctuations daily	Constant 22,000 cfs
Constant 25,000 cfs	22,000 cfs with fluctuations
25,000 cfs with daily fluctuations	Constant 40,000 cfs
Steady 40,000 cfs	Reduction in beaches
Double chance for a trophy size fish	
Double chance of not catching fish	

* No 13,000 cfs scenario with fluctuations was included for white-water boaters because it was impossible to word a scenario that sounded sufficiently different from the 22,000 cfs with fluctuations scenario to justify including it as a separate question.

VALUATION OF FISHING UNDER ALTERNATIVE FLOWS

Figure 1 summarizes the resulting values for fishing trips as a function of flows. The vertical axis shows consumer surplus per trip as a function of discharge rates along the horizontal axis. Because flows tended to be rather high and constant during the months of 1985 when the bulk of our sample was fishing, Figure 1 portrays values for scenarios, rather than values for flows actually experienced. The solid "flow-value function" reflects the values for constant flows and the broken line, for fluctuating flows. Interior points (3,000 to 40,000 cfs) connected by the solid line are values for constant flow scenarios listed back in Table 3. End points on the solid line (i.e., points at 1,000 cfs and 45,000 cfs) were determined through linear extrapolation of the lines connecting the nearest scenario points. The broken flow value function connects the scenario values for fluctuating flows. Since there was not a statistically significant difference between the values for constant and fluctuating flows at 3,000 cfs, the value at that point is shown as common to both flow-value functions. Constant and fluctuating flow values at 10,000 cfs and 25,000 cfs were statistically different at significance levels of 0.01 and 0.05, respectively. Differences between neighboring points on each of the flow value functions were also statistically significant at the .05 level or better.

Thus, we concluded that dam operations do have a significant effect on fishing. The consumer surplus per trip was $60 ($24 per day) at 3,000 cfs. The value rises steadily with higher flow levels, reaching a peak of $126 ($50 per day) at 10,000 cfs constant flows. Thereafter, the value of the experience drops steadily at higher flows, declining to $64 per trip ($26 per day) for constant flows at 40,000 cfs and even lower at 45,000 cfs. Ideal

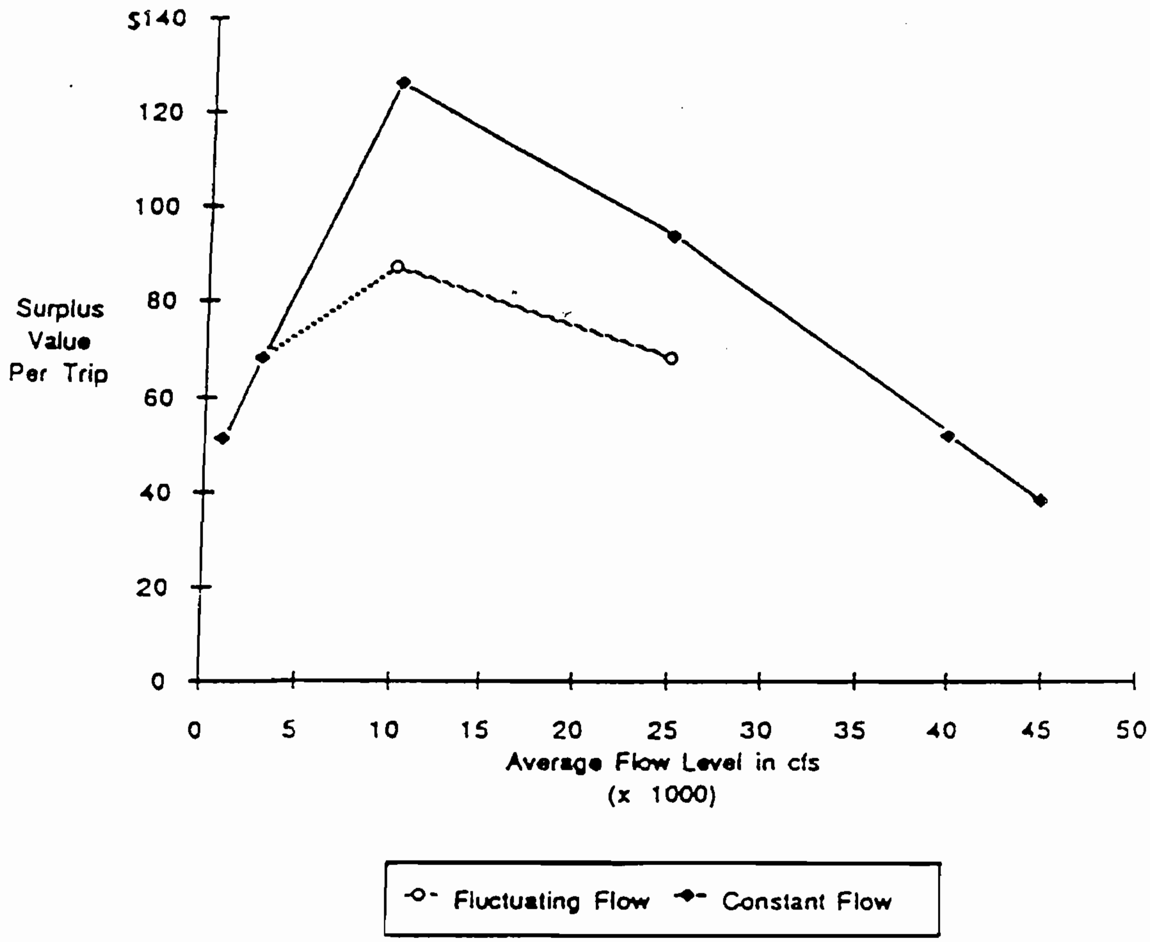


Figure 1. Glen Canyon Fishing Quality.

flows for fishing are in a range around 10,000 cfs, and constant flows are better than fluctuating flows except at very low average daily flows. Fluctuating flows reduce the surplus values per trip by as much as 30 percent.

Judging from the results of the attribute and contingent valuation surveys, these changes in consumer surplus appear to reflect a number of effects. Lower water is desirable because it concentrates the fish and is believed to produce better fishing. (Historical biological data from Glen Canyon tends to support the conclusion that fishing is better at low to medium flows.) However, at very low water, below 3,000 cfs, it becomes difficult or impossible to cross Three Mile Bar, a rock and gravel bar three miles upstream from Lees Ferry, with motor boats, thus restricting fishing to a much smaller area. Grounding boats and striking motors on rocks is also more frequent at low flows. Thus, very low flows are undesirable.

On the other hand, high water disperses the fish, which may reduce fishing success. It also creates stronger currents, increasing problems for boat handling. Tradeoffs among these countervailing impacts result in 10,000 cfs receiving the greatest surplus value, with fishing value declining both above and, more rapidly, below this flow level.

Large fluctuations require anglers to operate part of the day at low or high flows, with the attendant disadvantages of both. Changing water levels add additional difficulties. Falling water may make it difficult to get downstream over rocks and gravel bars that had more water over them on the trip upriver. Rising water may increase the likelihood of swamping a boat while anchored or while the bow is pulled up on shore. A few anglers did favor fluctuating flows because they believed that rising water may stimulate feeding by fish. Nevertheless, the majority of anglers felt that the disadvantages of fluctuations outweigh the advantages, except at very low flows.

VALUATION OF WHITE-WATER BOATING UNDER ALTERNATIVE FLOWS

Figure 2 shows flow-value functions for white-water boating. Here the broken lines express values for commercial trips, while the solid lines apply to private trips. The curves that increase to a maximum and then decline apply to constant flows while the straight lines show values for fluctuating flows. Like the fishing results, the flow-value functions for fluctuating flows connect points reflecting values for scenarios, with extrapolations to slightly higher and slightly lower mean flows. On the other hand, the flow-value functions for constant flows are based on flows that respondents had actually experienced.[8] Flow was a predictor of the yes/no responses to the contingent valuation question about the value of the actual trip for both commercial and private boaters at the 0.10 level of significance.

Thus, we conclude that dam operations do have a substantial effect on the value of the experience and that the effect is similar for private boaters and commercial passengers. The lowest consumer surplus values are produced at very low average daily flows. For example, at 5,000 cfs, private boaters received an average of $176 and commercial boaters $233 in consumer surplus per trip. This amounts to about $10 per day for private boaters and $30 per day for commercial boaters. The value of the trip rises steadily as flow levels increase. Private boaters received maximum consumer surplus, on average, at approximately 29,000 cfs, which results in roughly $700 per trip

[8]The range of flows actually experienced ranged from 10,500 cfs to 44,400 cfs. Thus, the flow value functions shown in Figure 2 do represent extrapolation of the results beyond the range of the data for flows between 1,000 cfs and 10,500 cfs.

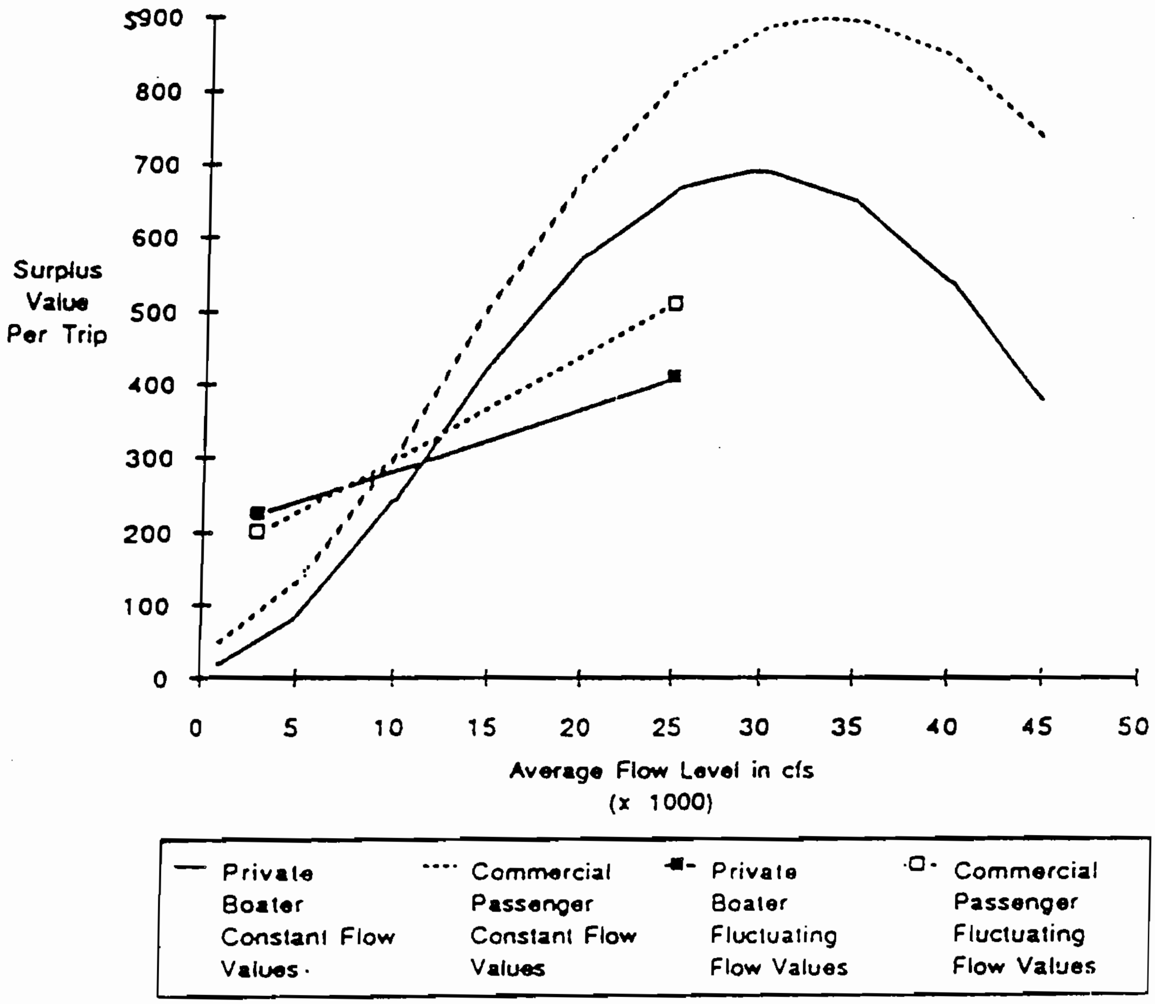


Figure 2. White-water Boating Quality.

($41 per day). Commercial passengers prefer approximately 33,000 cfs, which results in roughly $900 in consumer surplus per trip ($115 per day). Surplus values for commercial passengers were not affected by the type of boat they used. At flows above these preferred levels, the value of the experience falls off, but more rapidly for private boaters than commercial passengers.

These changes in recreation value appear to reflect the effects of average flow levels on important trip attributes. Time at attraction sites, such as Indian ruins and side canyons with pleasing scenery, and for layovers, depends on the speed of the current. The size and number of rapids are affected by dam releases. Boaters, particularly those on commercial trips, enjoy fairly large rapids that depend on substantial flows. At relatively low flows and flood flows, passengers, particularly those on commercial oar-powered trips, may have to walk around rapids. This is generally considered undesirable by passengers. Flood flows may raise concerns about safety in the minds of some boaters. Some risk at rapids makes the trip more exciting, but higher flood flows (say, 40,000 cfs and above) may be perceived as too hazardous for many. The lack of crowding is also important to many boaters. High and flood flows can contribute to crowding at campsites and attraction sites by inundating beaches. Both the guide survey and the attribute survey results agreed closely with the contingent valuation conclusions, increasing our confidence that these results are valid.

As can be seen for both private and commercial boaters, the presence of significant river fluctuations reduces the value of the experience, except at average daily flows below 10,000 cfs, where fluctuating flows are preferred to low constant flows. At higher flows, values may be lower by 25 percent or more for trips with fluctuating flows compared to constant flows at the same average daily flow. One of the primary attributes of white-water boating is experiencing the natural environment of the Grand Canyon. Attribute survey results indicate that perceptible fluctuations in water level make the canyon seem less natural to many participants. Allowing for changes in water level makes camping and mooring of boats for the night more difficult as well. Moored boats must be checked during the night to avoid being stranded on beaches in the morning. Fluctuations also increase the likelihood of arriving at rapids at disadvantageous times, when waiting for water-level changes or walking around a rapid may be necessary. Careful scouting of rapids may be required. Running rapids during the low flows associated with fluctuations increases the risk that boats will get hung up on rocks. Being stuck on a rock may mean only a minor inconvenience, but can mean disaster for the trip if the boat is seriously damaged or injuries are sustained in trying to free it.

At average daily flows below 10,000 cfs, higher dollar values for fluctuating flows than for constant flows also seem consistent with the survey data. At such low average flows, there is a desire to have flow rates in excess of 10,000 cfs for at least part of each day. For example, many rapids become more passable at higher flows and the ride becomes more exciting for most passengers.

OPTIONS FOR OPERATING THE DAM TO IMPROVE RECREATIONAL QUALITY

Having established that discharges from the dam do indeed affect recreation in significant ways, we turn to our second objective, defining how dam operations might be modified to improve recreational quality. Our method of proceeding will be to examine three actual years. "Water years" (WY) run from October 1 through September 30. Thus, WY 1989 will run from October 1, 1988, to September 30, 1989. The three years to be considered are WY 1982, WY

1984, and WY 1986. These years were chosen because they present a wide range of hydrological conditions under which to explore how dam operations might be modified to improve recreational quality. WY 1982 produced relatively low flows, with total releases of 8.2 million acre-feet. WY 1984 was a record year, with total releases of 20.1 million acre-feet. WY 1986 was an intermediate year, with total discharge of 16.6 million acre-feet.

In the analysis presented below, we calculated total consumer surplus from fishing and white-water boating under actual and hypothetical dam operating scenarios and resulting flow conditions. Values per trip were taken from the flow-value functions described in the preceding two sections. The per trip value for each month of the year was based on average monthly flow and whether that monthly flow was constant or fluctuating. Fluctuating flow months were those months for which the average daily maximum for the month exceeded the average daily minimum by 10,000 cfs or more. All calculations were made using the visitation rates from 1985 in order to hold this variable constant throughout the analysis. The assumption that the number of trips is not dependent on flow in the short run was based on known management practices and the survey results. Support for this assumption is particularly strong for white-water boaters since the National Park Service strictly regulates both the annual number of trips and the trip launching schedule. Flows could have more subtle effects on angler trips, but attribute survey results indicated that most anglers do not bother to inquire about actual flows when deciding whether or not to make a trip. Time off, the season of the year, weather, and other considerations seem to dominate the decision about whether or not to make a trip. Figure 3 shows the days of recreation by month for 1985.

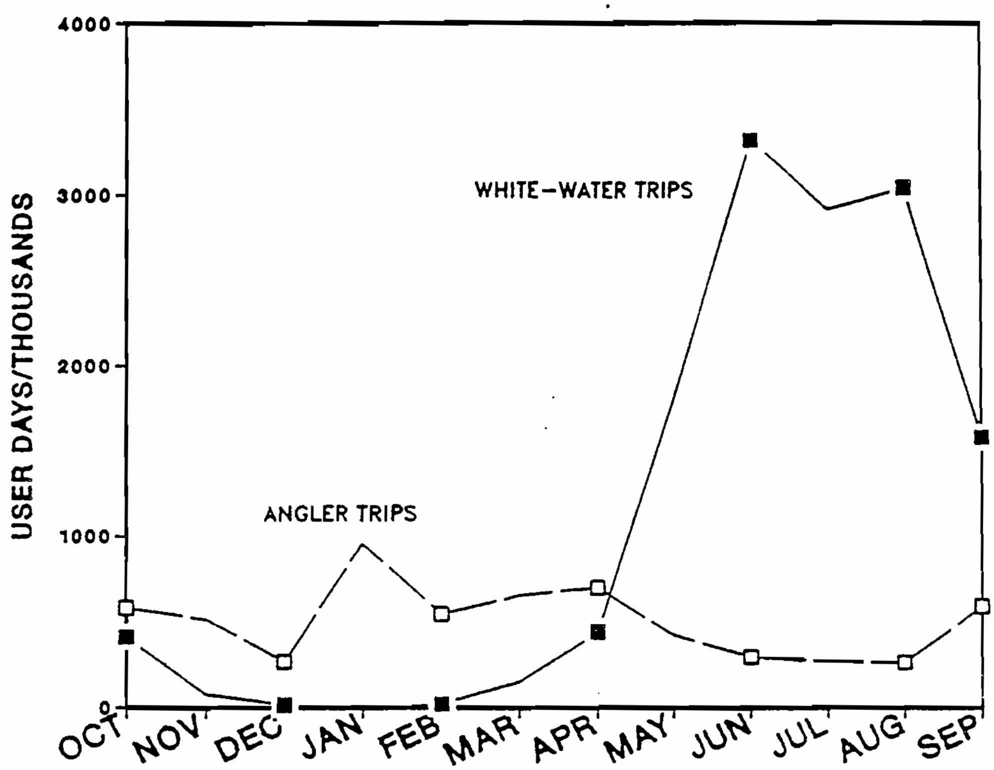
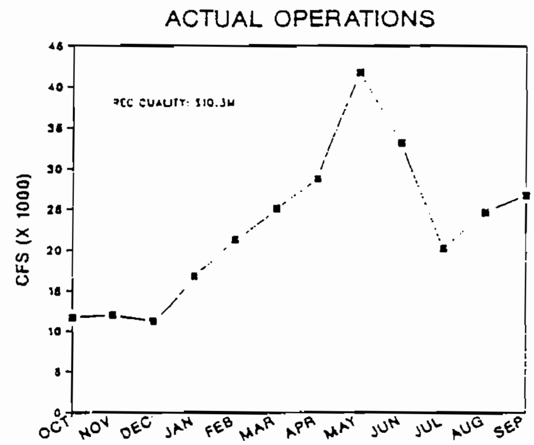


Figure 3. Recreation Use by Month for 1985.

The analysis proceeded in two steps. First, actual flows from the selected years were evaluated to serve as a baseline. Second, a set of scenarios was devised that would be approximately optimal from a recreational perspective. While we did not develop a formal optimization program, changes that would make substantial improvements in recreation were rather obvious. It is clear from the flow value functions that very low flows and very high flows adversely affect both recreational activities. Furthermore, fluctuating flows have an adverse effect except for the positive effects on white-water boating at average flows of less than 10,000 cfs. Thus, the approximately optimal scenarios constrained flows to be constant (thus avoiding reduced values due to fluctuations) at rates greater than or equal to 10,000 cfs (thus avoiding extremely low flow) and less than or equal to 31,500 cfs (thus avoiding flood flows in excess of power plant capacity). Additional steps toward a full optimum involved reallocations of water between months. Referring again to Figure 3, notice that fishing is distributed somewhat evenly throughout the year with small peaks occurring in the late fall, winter and early spring, while white-water boating is concentrated in the months between May 1 and September 30. Recall also the largest values per trip for white-water boating occur at flows toward the high end of power plant capacity, in the neighborhood of 29,000 to 30,000 cfs. Anglers, on the other hand, do best at moderately low flows, in the neighborhood of 10,000 cfs. Therefore, subject to the constraint on annual discharge and subject to the constraints on floods, low flows, and fluctuations, the approximately optimal scenarios reallocate water from the major fishing months to the white-water boating months.

Figure 4 illustrates the scenarios using the intermediate discharge year, WY 1986. Actual operations involved low flows, which were nearly ideal



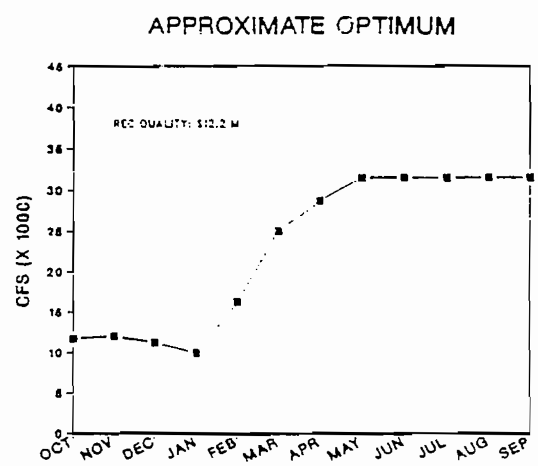


Figure 4. 1986 Water Year Monthly Flows.

for fishing, in the late fall and early winter. Dam releases then grew steadily through the rest of winter and into spring, peaking with flood flows in May. Thereafter, flows were at moderate levels, well below ideal levels for white-water boating during the last three months. The approximately optimal scenario maintains low flows for fishing through January, but reallocates the peak flows to provide better conditions for white-water boating, particularly in the May-through-September period.

Consumer surplus values for the three water years are shown in Table 4, in both dollar and percentage terms. A number of insights are immediately apparent. First, recreational use of the Colorado River below Glen Canyon Dam is capable of providing millions of dollars in recreation benefits. Depending on water availability and how the dam is operated, consumer surplus exceeding $12 million may be generated. Second, whether actual operations or the approximately optimal scenarios are considered, more water increases the value of recreation. This is because of the preferences of white-water boaters for relatively high flows. In years when total discharge is low, there is not enough water to provide good to excellent white-water boating conditions. Third, operating the dam under current criteria does have a substantial adverse impact on recreational quality in low- and moderate-discharge years. Operating the dam according to approximately optimal (from a recreational perspective) criteria under conditions existing in our low-discharge year (WY 1982) would increase aggregate consumer surplus by $2.0 million, a 42 percent increase compared to actual operations. For our moderate discharge example (WY 1986), consumer surplus increased by $1.9 million or 18 percent. Though small in percentage terms, even under high discharge conditions, management approaches catering more to recreational preferences would yield some increase in consumer surplus, about $700,000 in our 1984 case.

Table 4. Aggregate Consumer Surplus Under Alternative Dam Operation Scenarios in Millions of Dollars (Numbers in parentheses are percentage changes relative to actual operations).

Scenarios	Low Discharge Year (WY 1982)	Moderate Discharge Year (WY 1986)	High Discharge Year (WY 1984)
Actual Operations	$4.8	$10.3	$11.6
Approximately Optimal Scenarios	$6.8 (+42%)	$12.2 (+18%)	$12.3 (+6%)

The values in Table 4 can be used to evaluate how close the approximately optimal scenarios come to fully optimal ones. Bishop, et al. (1987) calculated an unconstrained optimal flow regime as part of the study we are drawing upon in this paper. That is, they asked what sorts of discharge rates by month would produce maximum aggregate consumer surplus assuming that water was available in any quantity at any time. The result was aggregate consumer surplus of $12.4 million. Producing such an optimum required 18.2 million acre-feet of water. This compares well with Table 4, where approximately optimal strategies produced $12.2 million in a 16.6 million acre-foot year (WY 1986) and $12.3 million in a 20.1 million acre-foot year (WY 1984).

One other relevant aspect, not visible in Table 4, needs to be reported. Fishing tends to fare poorly in actual operations regardless of annual discharges. In low-discharge years, flows tend to fluctuate, reducing fishing quality. In moderate and high-discharge years, fluctuations are less often present, but flows tend to be higher than would be ideal for fishing. As a result, fishing values tend to fall in a fairly tight range around $500,000 across a wide distribution of annual discharges under current operations, whereas they could go as high as $700,000 or more under scenarios where only fishing is considered. Interestingly, fishing does not fare much better in approximately optimal scenarios where fishing values and white-water values are combined. Because white-water boating is more valuable per trip, once the number of boating trips begins to pick up in April and May and as the boating season continues into September, white-water boating tends to dominate fishing economically.

CAVEATS

The potential modifications in dam operations evaluated here have been designed to explore the implications of our own, rather narrowly defined study for dam operations. The only constraint imposed on the approximately optimal scenarios was that they pass through the dam the same total amount of water as was passed through in the reference water year. No consideration has been given to other constraints on dam operations, such as the level of the reservoir at the start of the water year, the timing of spring runoff, or other demands for water storage or power generation--the dam's primary functions under current laws. Neither have we considered any long term effects of dam operations on recreational opportunities on Lake Powell or environmental quality upstream. A full analysis of the alternatives would have to go far beyond the recreation values studied here. Thus, the dam operating criteria under the approximately optimal scenarios should not be viewed as proposals for actual operations.

Furthermore, our results reflect recreation as it existed in 1985. In effect, we asked how much consumer surplus would have been generated if the various scenarios had occurred in 1985.[9] In that year, however, participation in fishing was substantially below the peak level established in 1983. Furthermore, significant changes in economically relevant parameters were recorded shortly after completion of our study. We are in the process of re-evaluating the fishery at this time. However, we doubt that our major conclusions will change much as the new data are analyzed. White-water boating participation in 1985 seemed typical of recent years, but the National Park Service is currently considering a new management plan for Grand Canyon river recreation that could make the future at least somewhat different from the recent past.

Ideally, dam releases would have been manipulated so that our contingent valuation survey respondents could have actually experienced a wide variety of constant and fluctuating flows. This was not possible, and we had to fall back on scenarios that asked respondents to imagine what their trips would have been like under different flows than they actually experienced.[10] As was explained above, the scenarios were carefully constructed based on attribute survey results, surveys of white-water guides and trip leader, and informal contacts with fishing guides and resource managers. Contingent valuation questions based on scenarios produced values that were sufficiently valid to justify the analyses conducted and conclusions drawn here. However, values based on actual experiences of recreationists would have been better.

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[9]Interestingly, calendar year 1985 looked much like WY 1986. The total water discharged was 16.6 million acre-feet, and we would estimate that actual operations generated $11.3 million in consumer surplus.

[10]The only possible exception was white-water boating, where we were able to base the flow-value function on actual experience. Even there, however, the flows could not be designed to allow each recreationist to experience a wide range of flows.

The treatment of fluctuations in this study has been intended only as a first approximation. Intuitively, the effects of fluctuating flows on recreation should be different depending on the magnitude of the fluctuation and the average daily flow around which the flows fluctuate. This supposition is supported by the results of our White-Water Guide Survey. However, as a simplifying assumption, we classified all days as either constant flow days or fluctuating flow days based on whether the difference between the daily minimum flow and the daily maximum flow exceeded 10,000 cfs without regard to the average daily flow. We believe that our simplified view provided satisfactory first approximations of the effects of fluctuations on trip values, but much room exists for refinements.

Some strategies for reducing the adverse impacts of dam operations on recreation may be worth considering. For example, ways might be found to make forecasts of water release schedules more reliable and more readily available to recreationists. The potential implications of such a system were not explored in the present study.

CONCLUSIONS

What advice could we give dam managers, if they asked us what they could do to enhance downstream recreation, other objectives aside? (1) We would assure them that there is clear evidence that how they operate the dam does have significant effects on recreational quality, effects that translate into millions of dollars. (2) To enhance recreation, they should try to avoid extremes. Extremely low flows (flows significantly below 10,000 cfs), extremely high flow (flows in excess of power plant capacity), and extreme daily fluctuations (differences in daily releases of 10,000 cfs or more) are all detrimental. (3) To the extent possible while observing the limits outlined in (2), water should be reallocated to the summer months and, water permitting, to the late spring and early fall. In all except the highest discharge years, benefits of $1 million to $2 million would be forthcoming, compared to current operations, if these criteria were observed.

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