CHAPTER IV

Environmental Consequences

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This chapter describes and analyzes the impacts of alternatives considered in detail on the affected resources. The analyses are organized by resource: water, sediment, fish, vegetation, wildlife and habitat, endangered and other special status species, cultural resources, air quality, recreation, hydropower, and non-use value.

The linkages among these Colorado River system resources are described in chapter III. Where possible, the impacts described for each resource take into account the impacts on other related resources. For example, each alternative affects streamflows, which in turn affect sediment. Sediment affects vegetation, which in turn affects wildlife and habitat—all of which affect recreation.

The conditions that existed in 1990, prior to the Glen Canyon Environmental Studies (GCES) research flows and the subsequent interim operations, establish the baseline for analyses of effects (see "Chapter III, Affected Environment"). Some anticipated impacts are a result of the existence of Glen Canyon Dam and will occur in the future regardless of which alternative is implemented.

Existing information was used to develop the detailed impact assessments of the alternatives that follow. However, existing information is limited for some resources, as is knowledge of how changes in Glen Canyon Dam operations would affect these resources. For example, limited data permit opinions to vary concerning interactions between native and non-native fish and how operational changes would affect these interactions and ultimately resident fish populations. Endangered fish research, which may include experimental flows, would be developed through the adaptive management process to address these uncertainties. Endangered fish research may have additional consequences, and these potential impacts are evaluated in the summaries of the following sections on FISH and HYDROPOWER. Potential impacts on the other resources, which are expected to be minimal, are addressed later in this chapter under "Cumulative Impacts."

WATER

Issue:

How do dam operations affect the amount and quality of WATER available from Lake Powell at specific times?

Indicators:

Acre-feet of **streamflows**
Frequency and volume of **floodflows and other spills**
Reservoir storage in Lakes Powell and Mead
Acre-feet of annual **water allocation deliveries**
Acre-feet of **Upper Basin yield determination**
Chemical, physical, and biological characteristics of **water quality**

The area of potential impacts on water includes the Colorado River downstream from Glen Canyon Dam, Lakes Powell and Mead, and the Upper and Lower Basin States. Computer modeling studies projected operations for 50 years to determine long-term impacts and for 20 years to determine short-term impacts.

Analysis Methods

The Colorado River Simulation System (CRSS) was used in analyzing impacts on annual and monthly streamflows, floodflows and other spills, water storage, water allocation deliveries, and Upper Basin yield determinations for this environmental impact statement (EIS). CRSS is a package of computer programs and data bases designed to assist water resource managers in performing comprehensive long-range planning and operation studies. CRSS is used to address the many "what will happen if . . . " questions that arise from proposed changes in Colorado River operations, from proposed Colorado River Basin development, or from changes in present water use throughout the basin.

While earlier computer models for the Colorado River existed as early as the mid-1960's, CRSS stemmed from the need for a comprehensive model of the Colorado River Basin that would incorporate all areas of interest, including legislative requirements. Work on CRSS began in 1970, and—after 10 years of development, testing, and initial use—the model began to gain widespread use and support in the early 1980's. Today, CRSS is the most comprehensive and detailed simulation system of the Colorado River and serves as the Bureau of Reclamation's (Reclamation) primary tool in studying the river's operation.

The main CRSS module, which contains all of the operations logic, is the Colorado River Simulation Model (CRSM). Frequently, the terms CRSM and CRSS are used interchangeably; CRSS is used in this document to refer to the computer model. CRSS is described in relative detail in the publication, *Colorado River Simulation System, System Overview* (Schuster, 1985).

A computer model (peak-shaving model) developed by the Environmental Defense Fund was used for the hourly distribution of CRSS-projected monthly release volumes. These hourly distributions were produced for the No Action and Maximum Powerplant Capacity Alternatives and for each of the restricted fluctuating flow alternatives. Steady flow alternatives did not require this analysis because flows from hour to hour would be essentially steady. (The hourly distributions were done to supply information to the GCES). Those hourly projections are the basis for summaries of future flow patterns under the alternative dam operations. Peak-shaving is the concept whereby hydroelectric powerplants are used to serve (shave) the highest electric load (peak) during a 24-hour period.

For the purposes of comparison, CRSS projections were made for annual and monthly values under each alternative. Where appropriate, the peak-shaving model was used to predict future hourly flows and daily fluctuations. In the discussion below, projected differences among alternatives are compared to the baseline (no action). An overview of model results is included; more detailed results of model studies are presented in Appendix B, Hydrology.

Summary of Impacts: Water

Table IV-1 summarizes the projected effects of the alternatives on annual and monthly **streamflows, floodflows and other spills** (as indicated by annual streamflows), **reservoir storage, water allocation deliveries**, and **Upper Basin yield determination**. Hourly streamflows are the means of change rather than an impacted parameter and are discussed under each alternative.

Impacts of the alternatives on water issues are essentially the same as under the No Action Alternative, except for monthly flows and floodflow frequencies. Streamflows, reservoir storage, water allocation deliveries, Upper Basin yield determination, and water quality are affected only negligibly by the alternatives.

All of the alternatives except the No Action and Maximum Powerplant Capacity Alternatives include measures to decrease the frequency of flood releases from the dam. Two example methods for accomplishing this reduction are:

1. Providing more capacity by increasing the height of the spillway gates

2. Reserving exclusive flood control space in the reservoir by using lower storage levels

Under no action, Lake Powell elevations would not normally exceed 3700 feet. However, when the spillway gates were extended by 8 feet under emergency conditions in 1983, the lake elevation reached 3708.3 feet and inundated an additional 6,840 acres of land. (The extensions were subsequently removed.) Raising the height of the four spillway gates potentially would allow the

Table IV-1.—Summary of anticipated impacts on WATER during the 50-year period of analysis by alternative[1] [2]

WATER	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow[3]	Modified Low Fluctuating Flow[3]	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow[3]	Year-Round Steady Flow
Streamflows (1,000 acre-feet)									
Annual median streamflows	8,573	8,573	8,559	8,559	8,559	8,559	8,559	8,554	8,578
Monthly median streamflows									
Fall (October)	568	568	568	568	568	568	568	492	699
Winter (January)	899	899	899	899	899	899	899	688	703
Spring (May)	587	587	592	592	592	592	592	1,106	699
Summer (July)	1,045	1,045	1,045	1,045	1,045	1,045	1,045	768	699
Floodflows (>45,000 cfs)									
Frequency (years)	1 in 40	1 in 40	<1 in 100	<1 in 100	<1 in 100	<1 in 100	<1 in 100	<1 in 100	<1 in 100
Reservoir storage (1,000 acre-feet)									
Lake Powell									
Average end-of-analysis	17,463	17,463	17,605	17,605	17,605	17,605	17,605	17,605	17,646
Lowest	6,700	6,700	6,800	6,800	6,800	6,800	6,800	6,700	6,800
Lake Mead									
Average end-of-analysis	14,045	14,045	14,404	14,404	14,404	14,404	14,404	14,653	14,415
Lowest	8,200	8,200	8,100	8,100	8,100	8,100	8,100	8,500	8,100
Water allocation annual deliveries (1,000 acre-feet)									
Upper Basin average	4,562	4,562	4,562	4,562	4,562	4,562	4,562	4,562	4,562
Lower Basin average	8,090	8,090	8,075	8,075	8,075	8,075	8,075	8,078	8,087
Mexico average	2,133	2,133	2,126	2,126	2,126	2,126	2,126	2,111	2,109
Upper Basin yield determination (1,000 acre-feet)									
Upper Basin annual yield	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000
New Mexico interim annual excess	69	69	69	69	69	69	69	69	69
Water quality									
At normal reservoir level (>3590 feet elevation)	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect

[1] Assuming the increased storage capacity method of reducing flood frequency.
[2] CRSS computer model results (except for Upper Basin yield determination and water quality).
[3] Effects of habitat maintenance flows on monthly volumes are not included. Such flows would approximately double March or April volumes and reduce other monthly volumes 5 to 10 percent in years when the reservoir is low (about half the years). None of the parameters on this table would be affected.

level of Lake Powell to increase by 4.5 feet (to elevation 3704.5 feet) over no action. This increase would inundate an additional 3,710 acres (2-percent increase) for about 1 or 2 months at an expected frequency of once in 20 to 40 years. Since the 8-foot increase in 1983 did not affect Rainbow Bridge National Monument, this increase would not affect the monument.

Potential impacts on **water quality** were assessed based on analysis of existing limited data on chemical, physical, and biological processes influencing water quality in Lake Powell.

Under normal hydrologic conditions, changing release patterns under any alternative would not affect reservoir or release water quality. Under any alternative, greater amounts of certain constituents (salinity, nutrients, sediment, selenium, and mercury) enter Lake Powell than are discharged. Therefore, these constituents would tend to increase in concentration, primarily in sediment and deep reservoir waters that rarely circulate. Lead concentrations also would continue to increase, as a result of leaded fuels used in motorized recreation on the lake. Other factors, such as future Upper Colorado River Basin depletions, development, and land use, may also influence water quality in Lake Powell and downstream.

Extended droughts cause low reservoir conditions (Lake Powell storage at or below half its capacity, or less than elevation 3590 feet) 5 percent or less of the time. When this does occur, intakes may draw water from nearer the reservoir surface, and large areas of delta may be exposed.

As a result of these events:

- Release temperatures may increase by 3 degrees Fahrenheit or less
- Release lead and dissolved oxygen concentrations may increase
- Release salinity, nutrient, mercury, and selenium concentrations may decrease compared to hypolimnetic release concentrations

Unrestricted Fluctuating Flows

No Action Alternative

Streamflow. Annual, monthly, and hourly streamflows, daily fluctuations, and ramp rates would remain as defined in chapter II under the No Action Alternative and chapter III, WATER.

Projected annual release patterns are similar to the historic patterns summarized in chapter II. The average annual release would be 10.16 million acre-feet (maf), and the projected median would be 9.37 maf. The minimum release of 8.23 maf would be expected to occur about 30 percent of the time in the next 20 years and 46 percent of the time in the next 50 years. Projected monthly release volumes, presented in table IV-2, are similar to the historic patterns discussed in chapters II and III.

Table IV-2.—Projected median monthly release volumes under the No Action Alternative in 1,000 acre-feet

	20-year	50-year
Fall (October)	568	568
Winter (January)	1,045	899
Spring (May)	715	587
Summer (July)	1,032	1,045

The median monthly releases would range from 568,000 acre-feet in October to 1,045,000 acre-feet in July for the 50-year analysis. Figure IV-1 shows the 50-year projected distribution of monthly flows under all alternatives. Effects of habitat maintenance flows are not included in this figure.

The results of the peak-shaving model 20-year projections of daily minimum and daily maximum flows and daily fluctuations are shown in figures IV-2, IV-3, and IV-4, respectively, along with projections for the restricted fluctuating flow alternatives. Effects of habitat maintenance flows are not included in these figures. Under the No Action Alternative, the minimum releases are projected to be less than 3,000 cubic feet per second (cfs) about 26 percent of the days and less than 8,000 cfs about 90 percent of the days.

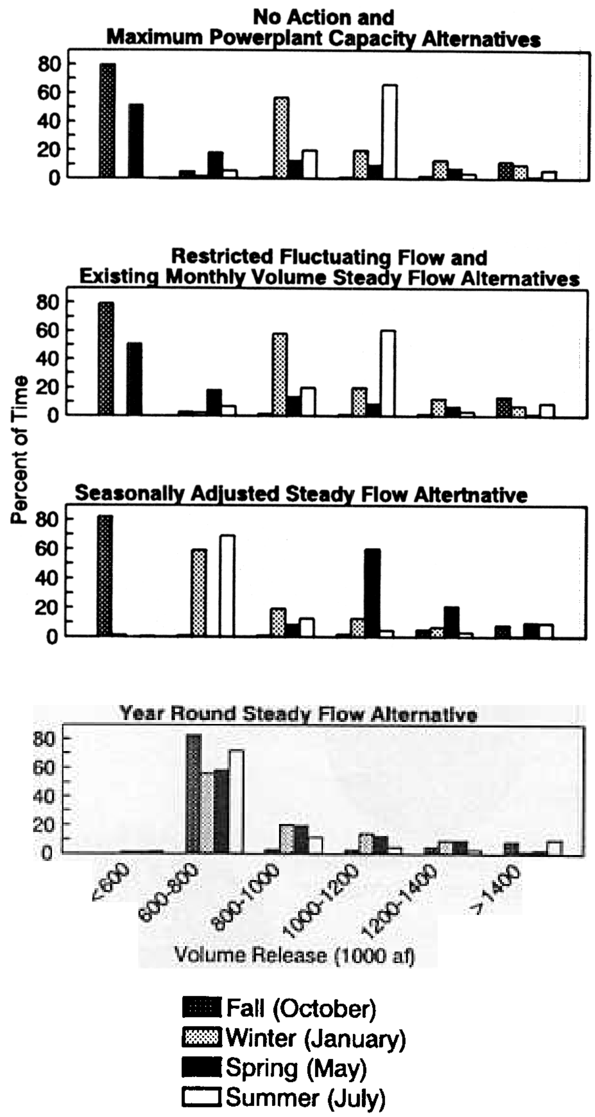


Figure IV-1.—Fifty-year projected distribution of monthly volume releases (flood frequency reduced by increasing height of spillway gates).

Maximum flows are projected to be greater than 25,000 cfs 14 percent of the days and greater than 20,000 cfs about 72 percent of the days. Daily fluctuations would be greater than 20,000 cfs about 13 percent of the days and greater than 8,000 cfs about 95 percent of the days.

Floodflows and Other Spills. Floodflows are releases in excess of the powerplant capacity of 33,200 cfs. Spills other than floodflows are excess annual releases from Lake Powell (greater than legally required) caused by scheduling difficulties—usually a substantial decrease in actual inflow from the initial forecasts.

Under the No Action Alternative, frequencies of floodflows in excess of 45,000 cfs are projected to be once in 30 years for the 20-year period and once in 40 years for the 50-year period of analysis.

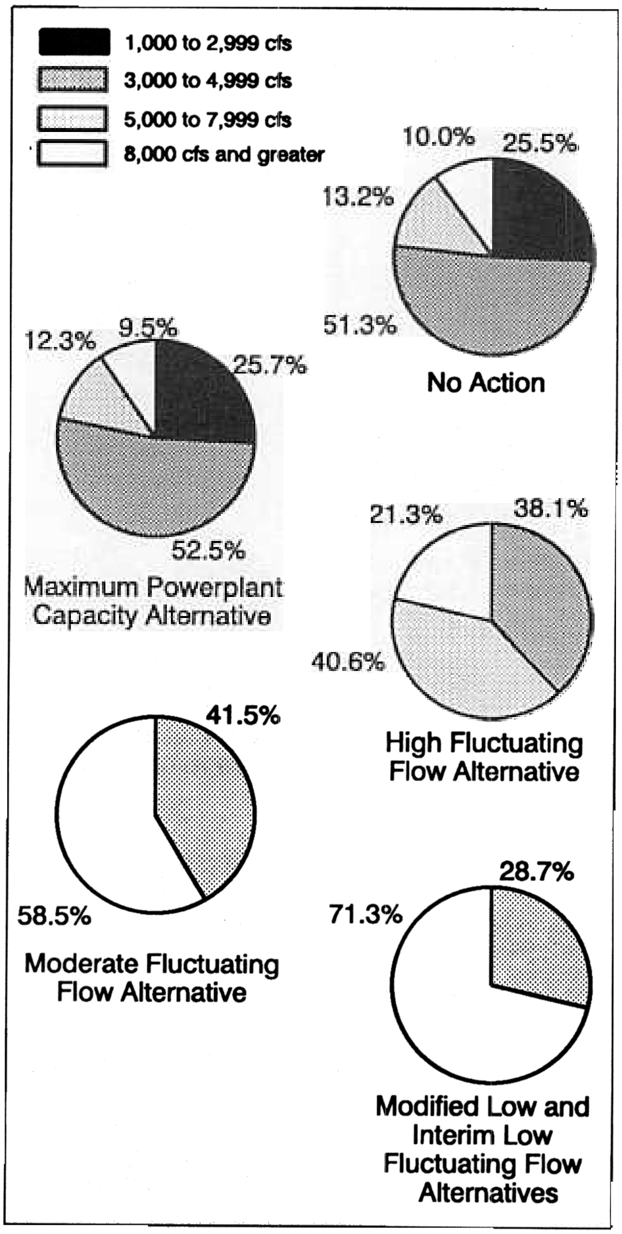


Figure IV-2.—Projected 20-year minimum hourly releases under the fluctuating flow alternatives (percentage of days that the minimums would occur).

(Frequencies of floodflows in excess of 33,200 cfs would be about once in 20 years for both the 20- and 50-year periods of analysis.)

Median annual water release patterns are used as indicators of the extent to which spills other than floodflows may be of concern under each of the alternatives. The expected no action median 20- and 50-year annual releases would be 9.4 and 8.6 maf, respectively.

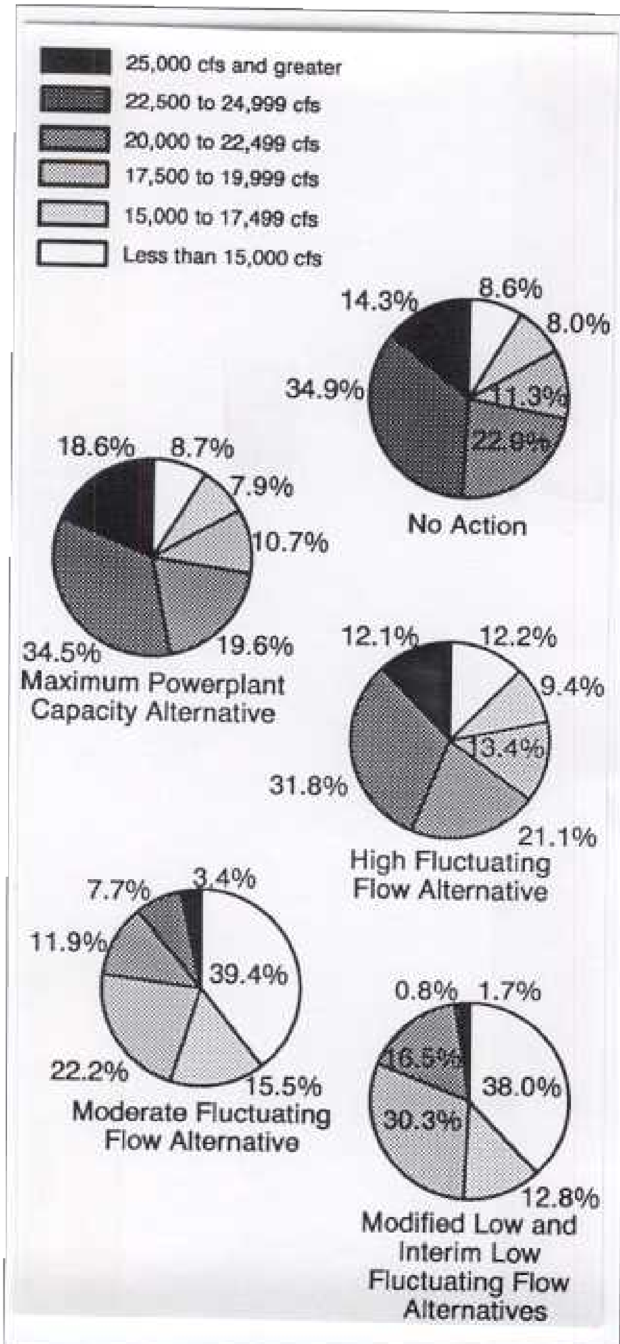
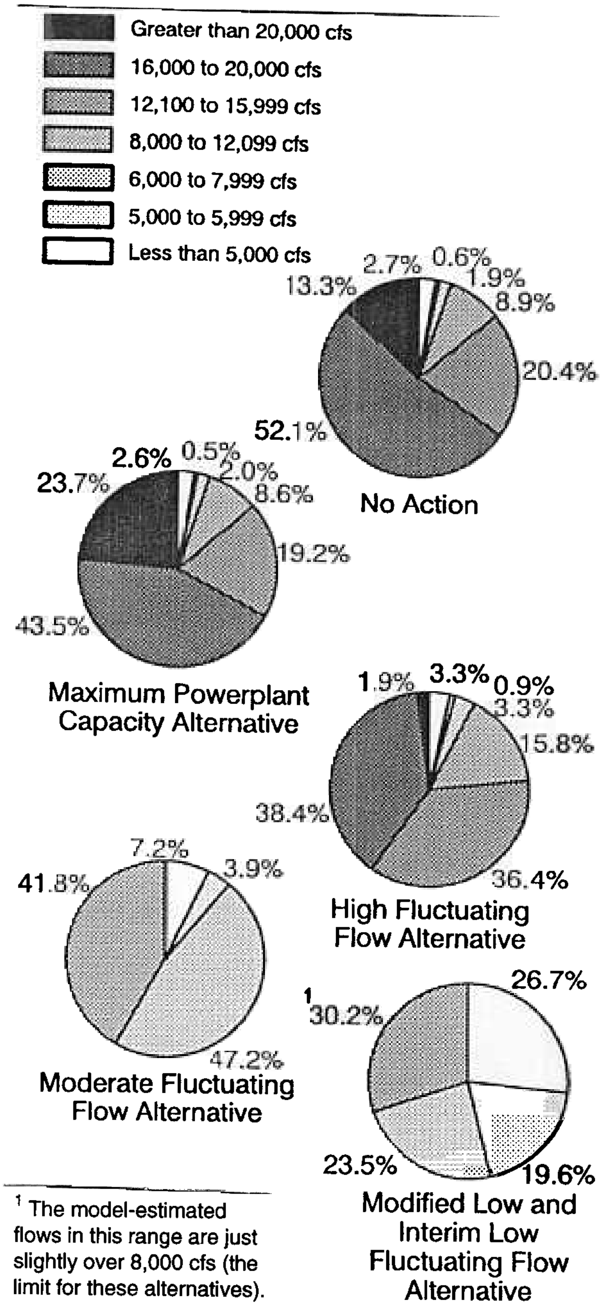


Figure IV-3.—Projected 20-year maximum hourly releases under the fluctuating flow alternatives (percentage of days that the maximums would occur).



[1] The model-estimated flows in this range are just slightly over 8,000 cfs (the limit for these alternatives).

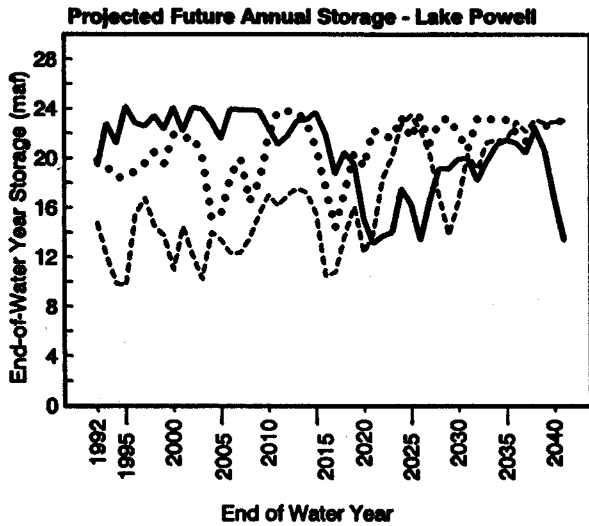
Figure IV-4.—Projected daily fluctuations under the fluctuating flow alternatives (percentage of days that the specified fluctuation would occur).

Reservoir Storage. Historic water storage in Lakes Powell and Mead was discussed in chapter III, WATER. Future storage levels are difficult to project because they depend on annual streamflow, which is highly variable and uncertain. The CRSS model used 85 possible future hydrologic scenarios (traces) in estimating future conditions. To demonstrate the possible range of future annual storage, storage levels under three hydrologic scenarios were plotted in figure IV-5 for Lakes Powell and Mead. Annual storage levels are projected to be essentially the same for all alternatives using either of the two methods of reducing flood frequency. The 85 scenario average end-of-analysis (20-year) Lake Powell storage is projected to be 18.6 maf, with the lowest projected at 9.5 maf. For the 50-year study, the corresponding figures are 17.5 and 6.7 maf, respectively. The corresponding Lake Mead storage is 18.7 and 9.4 maf for the 20-year study and 14.0 and 8.2 maf for the 50-year study.

Water Allocation Deliveries. Water apportionments among the Upper and Lower Colorado River Basin States are defined by the Colorado River Compact, and apportionments to Mexico are defined by treaty. The ability to provide these deliveries depends on maintaining conservation storage in and avoiding anticipated spills from Lake Powell.

Average annual Upper Basin consumptive use (excluding evaporation) is expected to be 4.2 maf and 4.6 maf for the 20- and 50-year periods of analysis, respectively.[1] Corresponding Lower Basin annual averages are 8.1 maf for both periods. The values for deliveries to Mexico are 2.2 and 2.1 maf, respectively. Tables III-5 and III-6 in chapter III show the historic Upper and Lower Basin and Mexico consumptive uses.

Upper Basin Yield Determination. The yield determination for the Upper Basin was discussed in chapter III. Under no action, the yield to the entire Upper Basin is determined to be 6.0 maf. The interim excess yield available to New Mexico from Navajo Reservoir is 69,000 acre-feet.



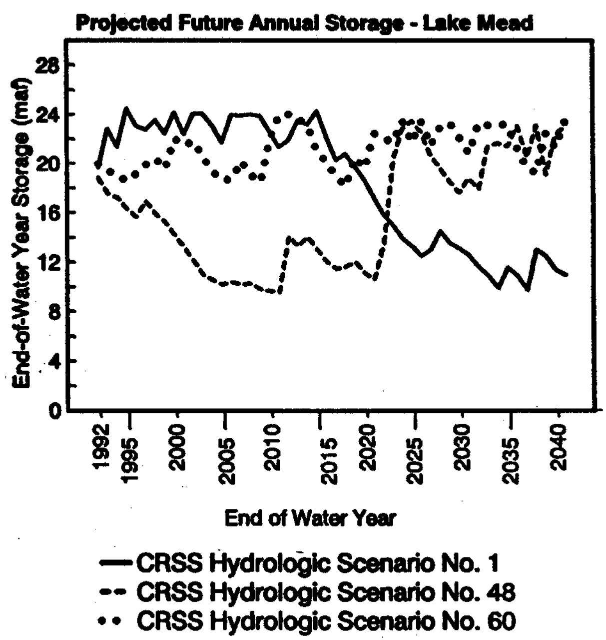


Figure IV-5.—Projected annual storage levels in Lakes Powell and Mead under three hydrologic scenarios.

Water Quality. Under normal or higher reservoir inflow and elevation, the No Action Alternative is not expected to further affect existing reservoir or release water quality.

[1] The maximum Upper Basin use of 6.0 maf (including evaporation) is not expected to be achieved until the year 2040.

Extended droughts (a natural hydrologic variation) that cause low reservoir conditions are expected to occur less than 5 percent of the time. The magnitude of such drought-related water quality changes would depend on the amount of reservoir drawdown and inflow, circulation, and other factors. As the reservoir refills and reaches normal levels, changes are expected to diminish.

Under low reservoir conditions, the intakes may withdraw water from nearer the surface in the middle layer, the metalimnion, or even the top layer, the epilimnion. Since water quality in the upper layers differs from that in the hypolimnion, changes in reservoir and release water quality would result.

A complete discussion of the effects of abnormally low reservoir conditions on water quality can be found in Appendix C, Water Quality.

Maximum Powerplant Capacity Alternative

Annual and monthly streamflow patterns under this alternative would be the same as under the No Action Alternative. The results of the peak-shaving model projections of daily minimum and daily maximum flows and daily fluctuations are shown in figures IV-2, IV-3, and IV-4, respectively. These hourly minimums, maximums, and fluctuations would differ little from no action.

Effects on **floodflows and other spills, reservoir storage** patterns, **water allocation deliveries, Upper Basin yield determination,** and **water quality** would all be the same as under the No Action Alternative.

Restricted Fluctuating Flows

The four restricted fluctuating flow alternatives would result in some common impacts, which are discussed in this section. Differences among alternatives are described under the individual alternatives that follow this section.

Hourly **streamflow** patterns under each of the restricted fluctuating flow alternatives would differ from those of the No Action Alternative (and those of each other) and are therefore discussed individually below. The annual patterns would be essentially the same as no action; monthly patterns would differ negligibly from no action, since the manner of scheduling monthly volumes would be the same. However, habitat maintenance flows (under the Moderate and Modified Low Fluctuating Flow Alternatives) and beach/habitat-building flows would about double March or April releases in years when the reservoir is low. Other monthly volumes would be reduced by about 5 to 10 percent under such circumstances.

Figure IV-1 shows the projected monthly patterns for the 50-year analysis without habitat maintenance or beach/habitat-building flows. Further, as shown in table IV-1, the projected median annual and monthly volumes are similar to those of no action. Tools are not available for projecting the frequencies of ramp rates, but ramp rates for all alternatives would be limited as defined in chapter II.

The expected frequency and magnitude of **floodflows** under the restricted fluctuating flow alternatives would be reduced to less than 1 in 100 years due to the addition of flood frequency reduction measures. Reclamation, in consultation with the Colorado River Management Work Group, would devise specific operating methods to achieve frequencies no greater than once in 100 years.

Annual water release patterns from Lake Powell have been used as an indicator of the extent to which **spills other than floodflows** may be of concern when flood frequency reduction measures are added. The projected median annual releases would be essentially the same as under no action for both the 20- and 50-year analyses using either method of reducing flood frequency. Therefore, the alternatives would have a negligible effect on spills other than floodflows.

Long-term monthly and annual **reservoir storage** would be the same under the restricted fluctuating flow alternatives as under the No Action Alternative for both Lakes Powell and Mead, except for slight differences due to addition of flood frequency reduction measures and habitat maintenance and beach/habitat-building flows. The lowest storage projected for the next 50 years would be the same as under the No Action Alternative for all restricted fluctuating flow alternatives. The end-of-analysis storages would be very nearly the same as no action (table IV-1). Generally, storage effects would be negligible to minor.

Water allocation deliveries under the restricted fluctuating flow alternatives would be essentially the same as under no action.

CRSS analyses indicated that under projected depletion levels, water allocation deliveries in the Upper Basin for the next 20 and 50 years would be affected negligibly by either of the methods of reducing flood frequency. However, if Upper Basin depletions would reach the levels permitted in the Colorado River Compact, a reduction in maximum allowable storage by reserving exclusive flood control space in Lake Powell would have a measurable impact on consumptive use. The reservoir system yield available for Upper Basin depletion would be reduced. This yield is defined as the sustainable annual quantity of water that could be depleted by the Upper Basin while making the required releases to the Lower Basin during periods of Upper Basin drought.

Using the critical 25-year hydrologic period 1953-77 and assuming full reservoir starting conditions, the current estimated annual **Upper Basin yield** is 6 maf. The impact of lower storage levels on yield can be estimated as follows: a 1-maf reduction in available storage would reduce the yield by 40,000 acre-feet per year (1 maf divided by 25 years). This would be only 0.67 percent of the total Upper Basin yield. Reducing flood frequency by increasing the height of the spillways would have no effect on Upper Basin yield determination. The increased spillway height method was assumed for impact analyses. U.S. Department of the Interior (1989) provides a more thorough explanation of yield methodology.

Effects on the Upper Basin yield limit the ultimate amount of water that each State in the Upper Basin can deplete. This is particularly critical in New Mexico, where uses are approaching their compact allocation. Thus, even though the Upper Basin yield would be reduced by only 0.67 percent, the water users who could receive a reduced or no allocation due to the overall reduction would be impacted substantially.

High Fluctuating Flow Alternative

Hourly **streamflow** patterns, daily fluctuations, and ramp rates would differ slightly from those under the No Action Alternative. The frequencies of minimum and maximum daily flows and daily fluctuations are summarized in figures IV-2, IV-3, and IV-4.

Moderate Fluctuating Flow Alternative

Hourly **streamflow** patterns, daily fluctuations, and ramp rates would differ from those under the No Action Alternative. The frequencies of minimum and maximum daily flows and daily fluctuations are summarized in figures IV-2, IV-3, and IV-4. The effects of habitat maintenance flows are not shown in these figures. However, such flows would increase the maximums and minimums and reduce fluctuations in March or April when the reservoir is low (about half the years).

During the habitat maintenance flow period, increases in turbidity are likely, which would decrease the depth that sunlight reaches in the water and thus affect **water quality**. Primary productivity may be temporarily reduced. However, resuspending sediment and organic material also may reintroduce nutrients and other constituents associated with the particles into the water. These nutrients may stimulate algal growth.

The river stage would not be significantly reduced by shifting water from one month to another for habitat maintenance flows. Thus, instream temperatures and *Cladophora* exposure would not change from no action.

Modified Low Fluctuating Flow Alternative

Hourly **streamflow** patterns, daily fluctuations, and ramp rates would differ from those under the No Action Alternative. The frequencies of minimum and maximum daily flows and daily fluctuations are summarized in figures IV-2, IV-3, and IV-4. The effects of habitat maintenance flows are not shown in these figures. However, such flows would increase the maximums and minimums and reduce fluctuations in March or April when the reservoir is low (about half the years).

The maximum allowable release under this alternative was increased from 20,000 to 25,000 cfs since the draft EIS was published. However, flows are expected to only rarely exceed 20,000 cfs during a minimum release year (less than 1 percent of the time). This is because the maximum allowable daily change constraint overrides the maximum allowable release and because monthly release volumes are lower during minimum release years.

Only when release volumes are between 0.9 and 1.5 maf could the maximum fluctuating release be between 20,000 and 25,000 cfs. During the 38 months of interim operations from August 1991 through September 1994 (minimum release years), all monthly volumes were less than 0.925 maf, and a total of only 3 months were greater than 0.900 maf. Historically (1963-89), monthly release volumes have been between 0.9 and 1.5 maf about 15 percent of the months.

Habitat maintenance flows would result in a **water quality** scenario similar to that described under the Moderate Fluctuating Flow Alternative.

Interim Low Fluctuating Flow Alternative

Hourly **streamflow** patterns, daily fluctuations, and ramp rates would differ from those under the No Action Alternative. The frequencies of minimum and maximum daily flows and daily fluctuations are summarized in figures IV-2, IV-3, and IV-4.

Steady Flows

Projected impacts to the water resource differ under each steady flow alternative. Therefore, no general steady flows discussion is presented, and results for each alternative are described individually.

Existing Monthly Volume Steady Flow Alternative

Annual and monthly release volumes under this alternative would differ negligibly from no action. **Streamflows** in the Colorado River below Glen Canyon Dam would be steady (subject to a plus or minus 1,000-cfs fluctuation for power system regulation), except during transitions from one month to the next. The median monthly values for 4 seasons are shown in table IV-3 along with their cfs equivalents. The second graph in figure IV-1 shows the monthly volume distributions for 4 representative months. Figure IV-6 shows the frequencies of flows for the same 4 months.

Floodflows and other spills under the Existing Monthly Volume Steady Flow Alternative would be the same as under the restricted fluctuating flow alternatives.

Table IV-3.—Existing Monthly Volume Steady Flow Alternative projected median streamflows

	20-year analysis		50-year analysis	
	1,000 acre-feet	cfs	1,000 acre-feet	cfs
Fall (October)	568	9,200	568	9,200
Winter (January)	1,021	16,600	899	14,600
Spring (May)	712	11,600	579	9,400
Summer (July)	1,012	16,500	1,045	17,000

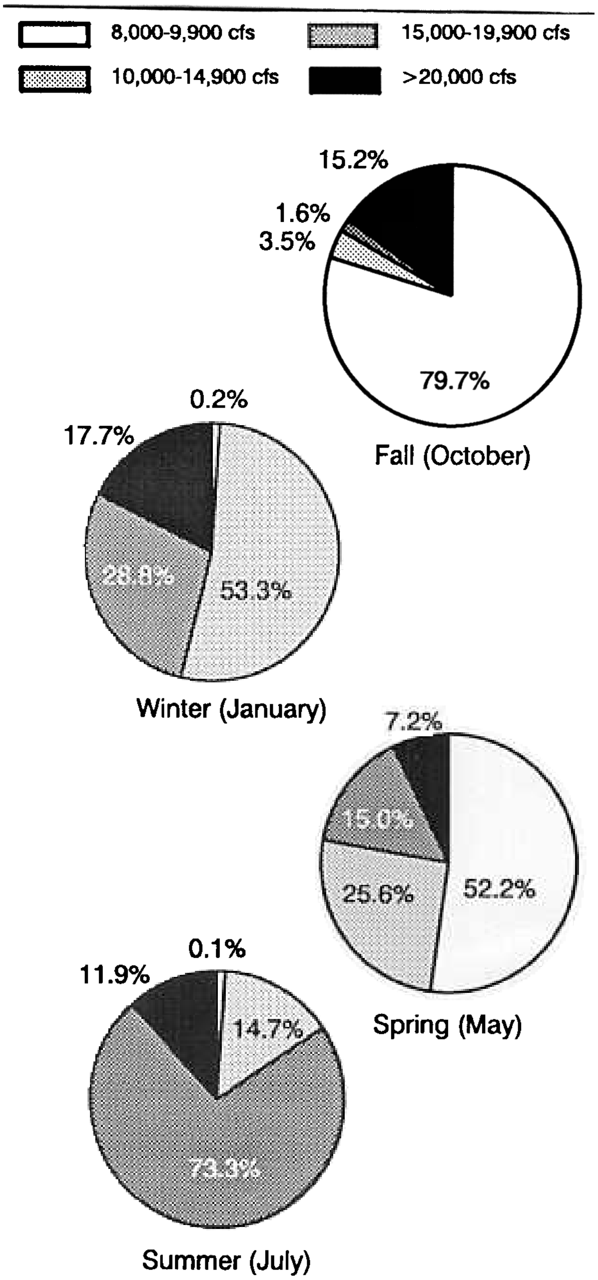


Figure IV-6.—Projected release patterns under the Existing Monthly Volume Steady Flow Alternative (50-year analysis, percent of months that specified releases are projected to occur).

Since monthly release volumes under the Existing Monthly Volume Steady Flow Alternative would be the same as they are under the restricted fluctuating flow alternatives, monthly and annual **reservoir storage** and the corresponding impacts on Lakes Powell and Mead would be negligible.

Monthly release volumes would be the same as under the restricted fluctuating flow alternatives, so impacts on **water allocation deliveries** under this alternative would be negligible. Also, the **Upper Basin yield determination** would be essentially the same as no action.

Water quality impacts would not vary substantially from no action. Steady, lower flows may allow for a relatively small increase in river temperatures, particularly during the summer, but this increase has not been quantified (see chapter IV, FISH). Temperatures in Lake Mead would not increase significantly.

Seasonally Adjusted Steady Flow Alternative

The annual release averages and medians would be the same as under the No Action Alternative using the increased spillway height method of reducing flood frequency and would differ negligibly using the lower storage method. Therefore, this alternative would have a negligible effect on annual releases.

Monthly release volumes are based on the steady schedules for the alternative as defined in chapter II. **Streamflows** would be steady, except during transitions from one month to the next. The median monthly values for 4 months are shown in table IV-4, along with their steady cfs equivalents. The fourth graph in figure IV-1 shows the monthly volume distribution for those 4 representative months. Also, figure IV-7 shows the frequencies of the steady flows in cfs for the same 4 months. The monthly distributions would differ in years when habitat maintenance or beach/habitat-building flows are scheduled. March or April volumes would about double, and other monthly volumes would decrease between 5 and 10 percent.

The expected frequency of **floodflows** under the Seasonally Adjusted Steady Flow Alternative would be reduced to less than 1 in 100 years

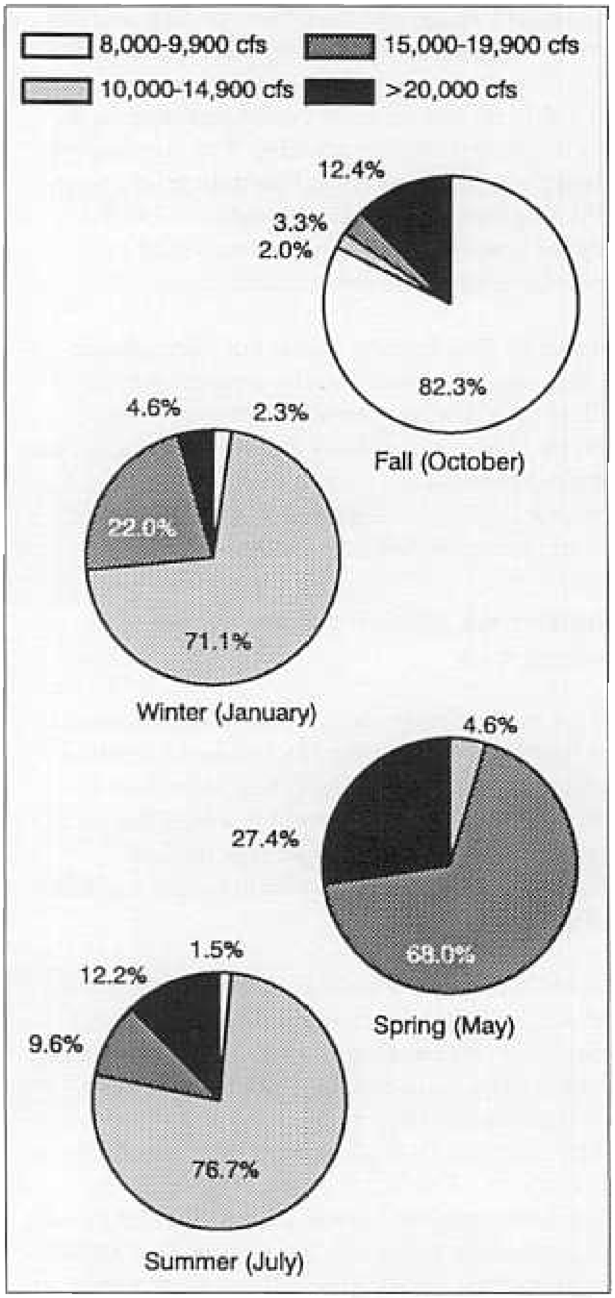


Figure IV-7.—Projected release patterns under the Seasonally Adjusted Steady Flow Alternative (50-year analysis, flood frequency reduced by raising spillway gates). Figure shows the percentage of months that the specified releases are projected to occur.

because of flood frequency reduction measures. Annual water release patterns from Lake Powell are used as an indicator of **spills other than floodflows**. The annual release patterns under this alternative would differ negligibly from the No Action Alternative.

Since monthly release volumes would be different under the Seasonally Adjusted Steady Flow Alternative than under no action, monthly **reservoir storage** (within each year) also would be different for both Lakes Powell and Mead. Median elevation differences at Lake Mead would be 4 feet lower in February and 4 feet higher in June than under no action . Median elevation differences at Lake Powell would range from about 4 feet more than no action in February to 4 feet less than no action in June. Figure IV-8

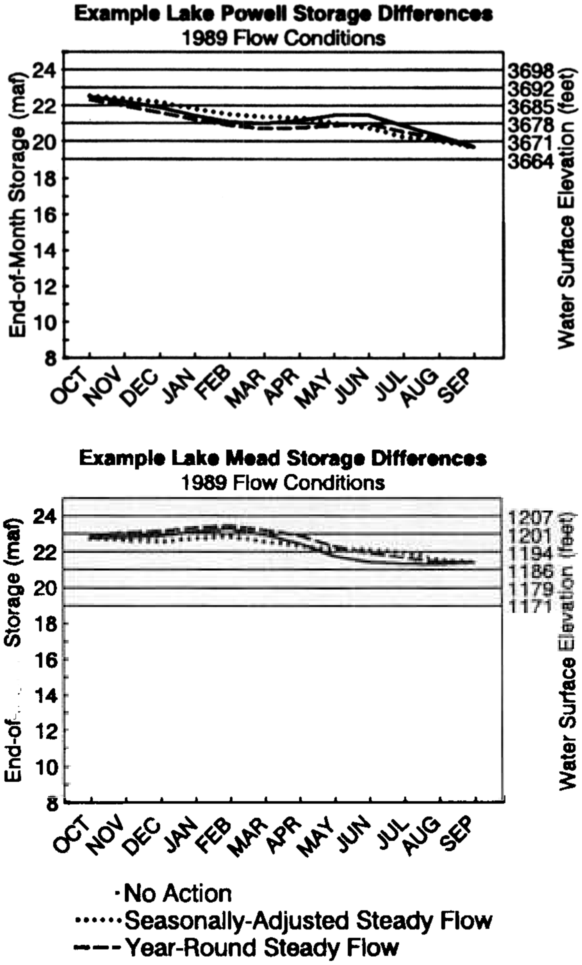


Figure IV-8.—Comparison of monthly storage (1989 flow conditions) under the steady flow alternatives and no action.

Table IV-4.—Seasonally Adjusted Steady Flow Alternative projected median streamflows

	20-year analysis		50-year analysis	
	1,000 acre-feet	cfs	1,000 acre-feet	cfs
Fall (October)	492	8,000	492	8,000
Winter (January)	798	13,000	676	11,000
Spring (May)	,156	18,800	1,106	18,000
Summer (July)	768	12,500	768	12,500

shows storage and elevation for the steady flow alternatives compared to no action for example water year 1989.

Detailed frequencies of monthly storages are presented in appendix B. End-of-analysis storage values would be nearly the same as no action for the lower rule curve method of reducing flood frequencies, but the lakes would see a 100,000- to 400,000-acre-foot increase in average end-of-analysis (50-year) storage using the increased capacity method. Lowest storage would be the same as under the No Action Alternative. The effects on annual storage would range from a negligible decrease to a minor increase over no action, depending on streamflow conditions.

Since monthly release schedules could be relaxed under high storage or inaccurate streamflow forecast conditions, **water allocation deliveries** under this alternative would be the same as under no action. Flood frequency reduction by increasing the height of the spillways would not affect water allocation deliveries. Upper Basin deliveries are projected to be the same as under the No Action Alternative. Lower Basin deliveries and deliveries to Mexico would differ negligibly from no action. **Upper Basin yield determination** would not be affected.

Water quality impacts would not vary significantly from no action under normal hydrologic conditions. Under low reservoir conditions, monthly reservoir levels would be approximately 2 to 8 feet lower than under no action from May through July. Additional reductions in reservoir levels due to seasonally adjusted steady flows may intensify impacts associated with low reservoir conditions (see discussion of water quality in chapter III and appendix C). As the reservoir refilled and reached normal levels, some of these impacts would be expected to diminish.

Steady, lower flows may allow for increased river temperatures, particularly during the summer, but this increase has not been quantified (see chapter IV, FISH). Greater minimum releases would increase flow depth, which may enhance *Cladophora* growth.

Habitat maintenance flows would result in a scenario similar to that described under the Moderate Fluctuating Flow Alternative.

Year-Round Steady Flow Alternative

The annual release averages and medians would be the same as under the No Action Alternative.

Table IV-5.—Year-Round Steady Flow Alternative projected median streamflows

	20-year analysis		50-year analysis	
	1,000 acre-feet	cfs	1,000 acre-feet	cfs
Fall (October)	699	11,400	699	11,400
Winter (January)	835	13,600	703	11,400
Spring (May)	820	13,300	699	11,400
Summer (July)	699	11,400	699	11,400

Monthly release volumes are based on the steady schedules for the alternative as defined in chapter II. **Streamflows** would be steady under the Year-Round Steady Flow Alternative, except during transitions from one month to the next. The median monthly values for 4 months in acre-feet and cfs are shown in table IV-5. The fifth graph in figure IV-1 shows the monthly volume distribution for those 4 representative months. Also, figure IV-9 shows the frequencies of flows in cfs for the same representative months.

The expected frequency of **floodflows** under the Year-Round Steady Flow Alternative would be reduced to less than 1 in 100 years by the addition of flood frequency reduction measures. **Spills other than floodflows** would differ negligibly from no action.

Since monthly release volumes would be different under the Year-Round Steady Flow Alternative than under the No Action Alternative, monthly **reservoir storage** also would be different within each year for both Lakes Powell and Mead. The monthly storage patterns within the year are found in appendix B. Median elevation differences at Lake Powell would range from about 3 feet less in June to no change from no action in September. Elevation differences at Lake Mead would be about the same except that the lake would be 3 feet higher than under no action in June. Figure IV-8 shows example storage and elevation differences for the steady flow alternatives compared to no action for water year 1989.

End-of-analysis storage values would be nearly the same as under the No Action Alternative for the lower rule curve method of reducing flood frequencies. With higher spillway gates, the lakes would have a 100,000- to 400,000-acre-foot increase in average end-of-analysis storage. Lowest storage would be essentially the same as under the No Action Alternative. Effects on annual storage would range from a negligible decrease to a minor increase, depending on streamflow conditions.

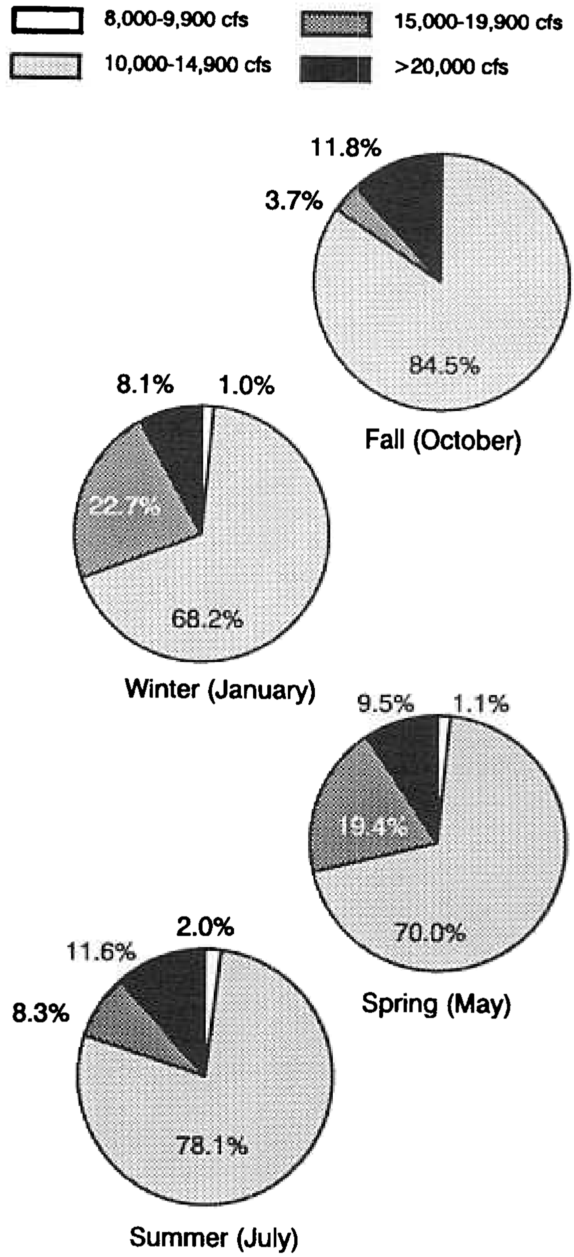


Figure IV-9.—Projected release patterns under the Year-Round Steady Flow Alternative (50-year analysis, percent of months that the specified releases are projected to occur).

Since monthly release schedules could be relaxed under high storage or inaccurate streamflow forecast conditions, **water allocation deliveries** under this alternative would be the same as under no action. Flood frequency reduction measures would not affect water allocation deliveries.

Upper Basin deliveries are projected to be the same as under the No Action Alternative; Lower Basin and Mexico deliveries would differ negligibly. **Upper Basin yield determination** would not be affected.

Impacts on **water quality** would be essentially the same as no action under normal hydrologic conditions. Under low reservoir conditions, monthly reservoir levels would be approximately 1 to 5 feet lower from May through July. Water quality changes would be comparable to those discussed under the Seasonally Adjusted Steady Flow Alternative.

SEDIMENT

Issue:

How do dam operations affect SEDIMENT throughout Glen and Grand Canyons?

Indicators:

Probability of net gain in **riverbed sand**
Active width and height of **sandbars**
Erosion of **high terraces**
Constriction of **debris fans and rapids**
Elevation of **lake deltas**

This analysis of impacts to sediment resources is limited to the following areas:

- Colorado River corridor between Glen Canyon Dam and Lake Mead
- Deltas in Lake Powell and Lake Mead

Direct impacts to sediment resources are those that vary with riverflow. These include changes in riverbed sand storage, aggradation and degradation of sandbars, and changes in capacity to move large boulders from rapids.

Short-term impacts to sediment resources would occur within 20 years after an alternative is implemented. Flood releases are assumed not to occur in the short term. In the absence of floods, sediment resources would be affected primarily by the magnitude, pattern, and duration of powerplant releases from Glen Canyon Dam.

Long-term impacts (20 to 50 years) would occur as sediment resources reached a state of dynamic equilibrium. Dynamic equilibrium means that the average sediment load transported by the Colorado River is in balance with the sediment loads being supplied by its tributaries. Sediment deposits (including sandbars) would increase and decrease in size and number as transport capacity and tributary supply varied, but monthly and annual changes would balance out, resulting in no net change over the long term.

Flood releases may result in immediate and potentially large changes that diminish over a decade. Floods transport sand stored in the riverbed, erode low elevation sandbars, aggrade and erode high elevation sandbars, and widen the channel at debris fans and rapids. Floodflows greater than 45,000 cfs are assumed to occur over the long term.

Analysis Methods

To the extent possible, a "system" approach, as discussed in the resource linkages section of this chapter, was used to evaluate impacts. Sediment resources, such as riverbed sand and sandbars, are linked—just as most other resources discussed in this EIS are linked to sediment. Impacts were analyzed on the basis of the following categories of information provided by the GCES program:

- Records of river stage, streamflow, and sediment discharge at U.S. Geological Survey (USGS) gauging stations along the river and on the principal sediment-producing tributaries
- Measurements and observations at selected sites during floods, various powerplant operations, specially designed research flows, and interim flows
- Scientific conclusions about depositional and erosional processes that result in riverbed sand storage changes
- Results from the CRSS and peak-shaving models (see WATER in this chapter)

A comprehensive, mathematical flow and sediment-transport model of the river and associated eddies is under development in GCES (Wiele and Smith, 1991; Graf et al., 1993). The model should be useful in the Adaptive Management Program. Some preliminary results from model development—wave transformation and reach-averaged hydraulic properties—were available for use in this impact analysis.

Sand deposits (and sand-dependent resources) are affected by the amount of riverbed sand transported under a given alternative. A long-term net loss of riverbed sand would result in long-term loss in the number and size of sandbars, with corresponding changes in aquatic and riparian habitat. Future changes in riverbed sand depend primarily on tributary sand supply and the magnitude, frequency, and duration of floods.

Riverbed sand also would vary with the water volume and release pattern of the alternative implemented. The exact amounts of future tributary sand supply and water release volumes are unknown but can be expressed using probabilities, as demonstrated by Smillie, Jackson, and Tucker (1993). A mass-balance model was developed to estimate the impacts to riverbed sand (Randle et al., 1993). This model used 85 different hydrologic scenarios (50 years each) to evaluate changes in riverbed sand. These scenarios matched projected releases from Glen Canyon Dam (based on historic flows in the Upper Basin from 1906 to 1990) with Grand Canyon tributary flows from 1941 to 1990. Details about this analysis and the assumptions used are described in Appendix D, Sediment.

Information is not available to predict impacts to individual sandbars. On the basis of empirical studies at specific sandbars, however, predictions can be made for comparison of alternatives. Long-term losses in the number and size of sandbars are assumed to result from a long-term loss of riverbed sand. That would occur if the sand-transport capacity of the river exceeds the long-term supply from tributaries.

Impacts to sandbars were determined using the principles of slope stability developed for Grand Canyon sandbars by Budhu (1992). An illustration of these principles is shown in figure IV-10. Sand and smaller-size sediment is deposited during high river stages at slopes of about 26 degrees. As the river stage recedes, this slope may be unstable due to seepage, high velocities, or wave action. Under any of these conditions, erosion would likely occur until a stable slope of about 11 degrees was achieved. Assuming sufficient quantities of riverbed sand, an eroded sandbar would likely rebuild during subsequent periods of high river stage.

The active width of a sandbar is that part of the bar subjected to cycles of deposition and erosion—the hydrologically active zone. Estimates of average active widths are computed from average differences in river stage corresponding to changes in discharge. The modeling effort by Randle and Pemberton (1987) was extended to compute average daily and annual differences in river stage by reach for each alternative (see appendix D). The results compared well with independent computations by Smith and Wiele (written communication, 1992) for a somewhat different delineation of reaches.

Summary of Impacts: Sediment

The impacts of the alternatives on sediment resources are summarized in table IV-6. Numerical values, based on sources of information previously listed, were used as indicators of impacts for all sediment resources.

Some uncertainty exists in the numerical values in table IV-6 and in the subsequent discussion of alternatives. Indicators of riverbed sand are mainly derived from modeling, and sandbar indicators are mainly the result of field surveys, modeling, and empirical data. Each has a different kind of uncertainty that cannot be stated quantitatively, due to insufficient information. In general, however, the uncertainty does not affect relative differences between alternatives.

General impacts to riverbed sand, sandbars, high terraces, debris fans and rapids, and lake deltas are discussed below. Specific impacts to these resources are discussed under each alternative.

Table IV-6.—Summary of anticipated impacts on SEDIMENT by alternative

SEDIMENT	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Riverbed sand (percent probability of net gain)									
After 20 years	50	49	53	61	64	69	71	71	74
After 50 years	41	36	45	70	73	76	82	82	100
Sandbars (feet)[1]									
Active width	44-74	47-77	33-53	28-47	24-41	24-41	10-19	16-29	0
With habitat maintenance flows				41-66	41-66			37-60	
Potential height[2]	10-15	10-16	7-11	6-10	6-9	6-9	3-5	4-7	0-1
With habitat maintenance flows[3]				9-14	9-14			8-13	
High terraces (adjacent to river)									
Frequency of flood erosion	1:40	1:40	1:100	1:100	1:100	1:100	1:100	1:100	1:100
Debris fans and rapids									
River's capacity to move boulders as a percentage of 1983 flood capacity	12	13	12	10	10	5	3	10	2
Lake delta (crest elevation in feet)									
Lake Powell	3662	3662	3662	3662	3662	3662	3662	3660	3660
Lake Mead	1167	1167	1167	1167	1167	1167	1167	1168	1168

All values calculated for 8.23 maf annual release and include effects of flood frequency reduction, as appropriate. Effects of beach/habitat-building flows are not included (see text).

[1] Active widths and potential heights do not take into account the availability of riverbed sand.

[2] Difference in water-surface elevations at minimum and maximum flow.

[3] Difference in water-surface elevations at minimum flow and 30,000 cfs.

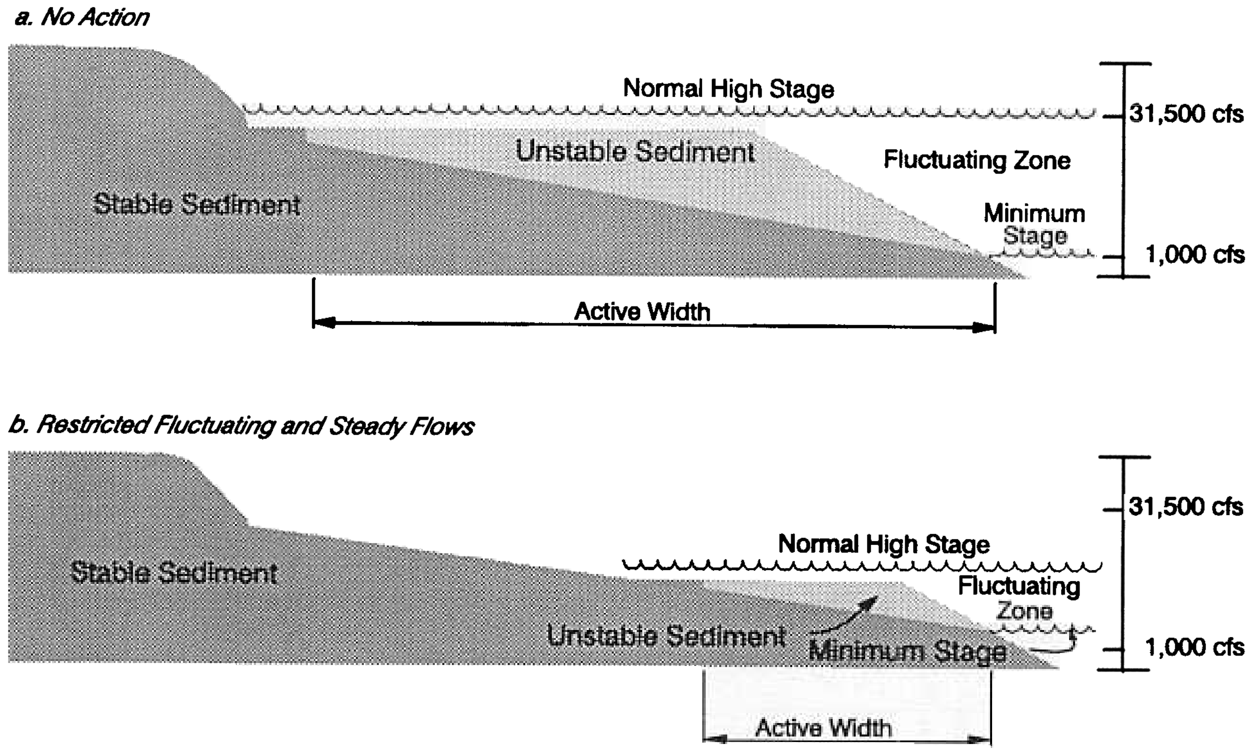


Figure IV-10.—Cross section of sandbar affected by no action and by restricted fluctuating and steady flows. As the fluctuating zone is reduced, so too is the zone of unstable sediment and sandbar heights.

The effects of flood frequency reduction are included in the analyses of the restricted fluctuating and steady flow alternatives.

Riverbed Sand

A long-term net loss of riverbed sand would result in long-term loss in the number and size of sandbars. In the Glen Canyon reach (river mile (RM) -15.5-0), there is essentially no resupply of sand, and that reach would only continue to lose sand under any alternative. However, remaining sand deposits in this reach are fairly well protected; therefore, future erosion rates would be relatively low and not measurably different under any alternative.

The reach between Lees Ferry (RM 0) and the Little Colorado River (LCR) (RM 61) is much more vulnerable to net sand loss than the river downstream from the LCR because of the limited sources of supply—mainly the Paria River (supply from LCR not included). From the LCR to Lake Mead, differences in riverbed sand storage between alternatives would be negligible on the basis of available sand transport equations for gauging stations in that reach (Pemberton and Randle, 1986).

The probabilities of a net gain in riverbed sand at the end of 20 and 50 years for the reach between the USGS gauges at Lees Ferry and the LCR are listed in table IV-6. Tables listing the probabilities of a net gain in storage in a low, moderate, and high release year (water years 1989, 1987, and 1984) are included in appendix D.

The probabilities were computed as described above under "Analysis Methods." The 20- and 50-year simulations include sequences of the wide variety of hydrologic conditions—normal, wet, dry—that occurred between 1906 and 1990. The probabilities are computed as the ratio of the number of simulations ending with a net gain in riverbed sand to 85 (the number of simulations). For both the 20- and 50-year periods, the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives have relatively low probabilities of a net increase in riverbed sand; all other alternatives have relatively high probabilities.

Sand transport capacity and probability of net gain in riverbed sand for each alterative are listed in table IV-7. The differences due to habitat maintenance flows also are listed for the three alternatives that include them. During a minimum release year, such flows generally would result in a net increase in sand transport capacity of about 30 percent and a decrease in the probability of net gain in sand storage of about 11 percent.

The following conclusions from a mathematical sand transport model developed under GCES by Bennett (1993) support basic assumptions used in this EIS to evaluate the impacts of the alternatives on riverbed sand and sandbars.

- For a given release volume, alternatives with greater flow fluctuations generally leave less total sand mass in the river channel but result in higher-elevation sandbars. Sandbars tend to aggrade during high flows and erode during low flows.
- Sand transport capacity increased more rapidly than sand supply when the annual release volume increased from 8.23 to 10.5 maf. This resulted in a net decrease in the amount of sand retained in the river channel but sandbar deposition at higher elevations within the eddy storage zones.
- A beach/habitat-building flow following a high fluctuating flow would deposit higher-elevation sandbars than when following a lower fluctuating or steady flow. Sandbars that start out higher will end up higher.
- Results are inconclusive concerning the optimum duration of the beach/habitat-building flow. Sandbars initially may build and later erode if the duration is too long (perhaps more than 2 weeks).

In all simulations, the amount of sand stored in the eddies is relatively small, seldom exceeding more than 30 percent of the total in the reach.

Sandbars (Beaches and Backwaters)

If sufficient quantities of riverbed sand are available, the tradeoff with sandbars under the various alternatives is whether to have higher bars with steeper, less stable slopes or lower bars with flatter, more stable slopes. Less stable sandbars would experience greater and more frequent cycles of deposition and erosion than more stable sandbars. As discussed in chapter III,

Table IV-7.—Sand transport capacity and probability of net gain in sand storage in the Colorado River between the Paria River (RM 0) and the Little Colorado River (RM 61), for a minimum release year (8.23 maf)

			Difference due to habitat maintenance flow	
Alternative	Sand transport capacity (1,000 tons)	Probability of net gain in sand storage (percent)	Sand transport capacity (1,000 tons)	Probability of net gain in sand storage (percent)
No action	517	47		
Maximum powerplant capacity	530	45		
High fluctuating flow	463	55		
Moderate fluctuating flow	434	58	+116	-12
Modified low fluctuating flow	424	59	+117	-11
Interim low fluctuating flow	307	70		
Existing monthly volume steady flow	259	77		
Seasonally adjusted steady flow	390	64	+124	-11
Year-round steady flow	196	82		

SEDIMENT, sandbars that existed prior to Glen Canyon Dam were very unstable—building during floods and rapidly eroding following the return to lower flows. Habitat maintenance and beach/habitat-building flows are intended to partly restore this natural process.

The long-term maintenance of sandbars requires deposition during high flows. Over the long term, the parts of sandbars higher than the peak river stage of an alternative (including beach/habitat-building flow) would experience net erosion. Erosion by wind, local storm runoff, and human activity would be about the same under all alternatives.

Eddy backwaters are dependent on the formation of reattachment bars. Initially, the number and size of backwaters would depend on the level of discharge (see FISH section of this chapter). However, return-current channels that form backwaters would tend to fill with sand, silt, and clay and re-form during the next beach/habitat-building flow or flood release. The addition of new silt and clay to the eddies would depend on maximum river stage and timing with tributary floods, which are most likely to occur during August-October.

Annual range of sandbar active width and potential height for the widest and narrowest reaches are shown for a minimum release year in table IV-6. Active widths are used as an indicator of areas generally not suitable for establishment of vegetation, although vegetation may grow in this zone if flow fluctuations are small. Complete tabulations of average sandbar active widths and heights for 11 reaches under each alternative are included in appendix D.

The potential sandbar heights listed on two lines of table IV-6 are differences between water surface elevations. These represent the range (between the widest and narrowest river reaches) in potential height of sand deposition if there is a sufficient supply. They also represent potential heights of silt and clay deposition, provided the high releases coincide with high flows from one or more major tributaries. One line lists differences between elevations under normal minimum and maximum flows for the alternatives. The other line lists differences between elevations under normal minimum flow and 30,000 cfs for the three alternatives with habitat maintenance flows.

The values in table IV-6 and the graphs in figure IV-11 show the general relationship between sandbar height and the probability of net gain in riverbed sand. Alternatives that include habitat maintenance flows have potential sandbar heights nearly the same as under no action, but with much higher probabilities of net gain in riverbed sand. Habitat maintenance flows would provide some dynamics of a natural system (deposition and erosion). Sand previously stored on the riverbed would be transported, and sandbar deposition would occur in low-velocity areas along the channel. Other deposits exposed to high velocities would be reworked and may experience net erosion. Overall, net deposition would be expected at higher-than-normal elevations. These new deposits would erode at an unknown rate following the return to more normal flows.

Beach/habitat-building flows might be as high as 45,000 cfs; more information is needed about the effects of these flows and the subsequent stability of the aggraded sandbars. Such information would be obtained from long-term monitoring and research under the Adaptive Management Program. Tables of potential sandbar heights for these flows in each of the 11 reaches under each alternative are included in appendix D.

Habitat maintenance and beach/habitat-building flows that coincide with large, sediment-laden floods from one or more tributaries could deposit silt and clay at higher elevations. Conversely, there could be a net loss of silt/clay if such high flows are not accompanied by tributary delivery of substantial amounts of silt and clay.

Downstream from RM 236 in Lower Granite Gorge, sediment deposition and erosion along the channel margins are primarily driven by changes in the level of Lake Mead (see discussion under "Lake Deltas").

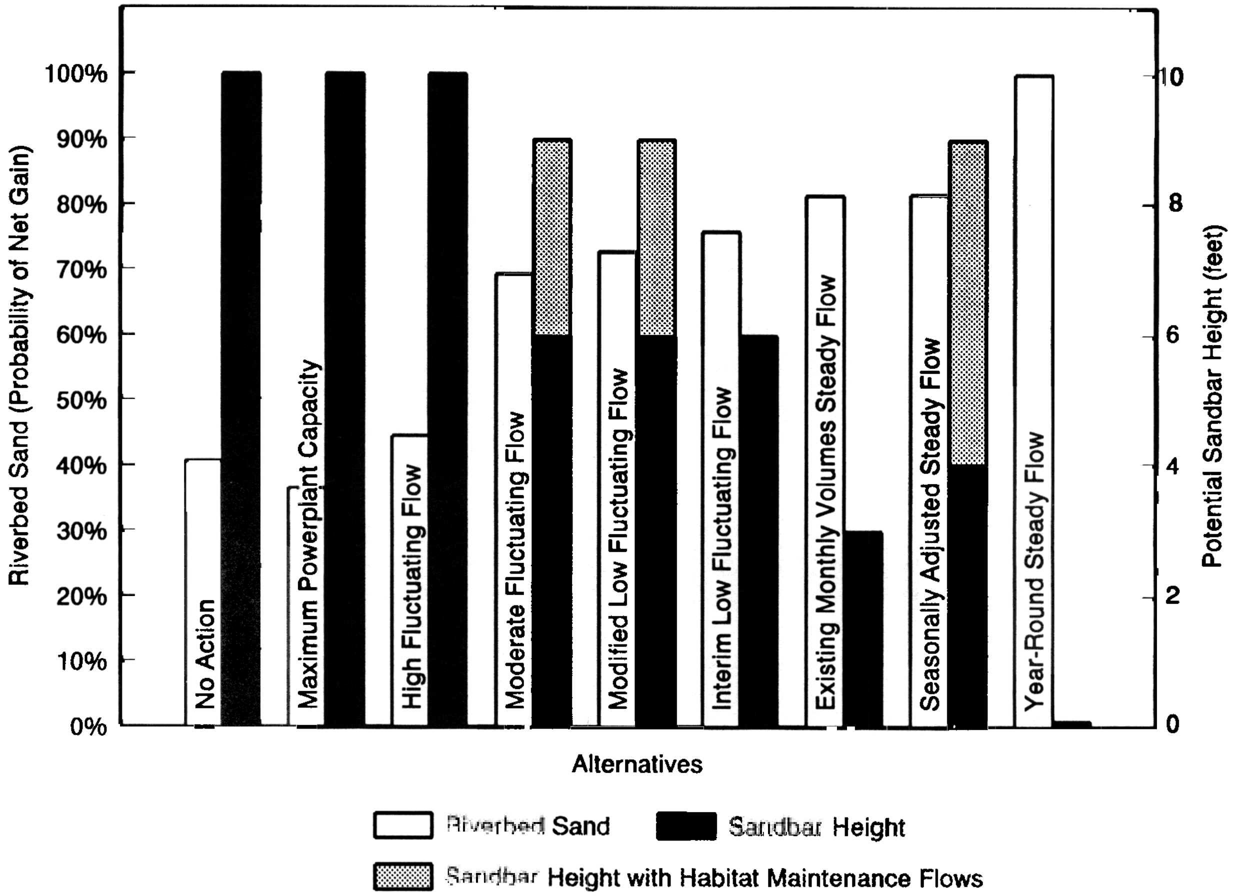


Figure IV-11.—Probability of a net gain in riverbed sand in reach RM 0-61 after 50 years and potential sandbar heights in wide reaches (without beach/habitat-building flows) for each alternative. The probability of a net gain in riverbed sand and the potential sandbar heights depend on the magnitude and frequency of an alternative's normal peak discharge. The No Action Alternative could potentially deposit high sandbars but would have relatively little sand to deposit. In contrast, the Year-Round Steady Flow Alternative would have ample riverbed sand to deposit but relatively little potential to deposit it at high elevations. Beach/habitat-building flows would infrequently increase these potential sandbars heights.

High Terraces

In the absence of extremely large sediment-laden floods (greater than 100,000 cfs), the fate of high terraces is gradual erosion, regardless of the alternative implemented (see chapter III, SEDIMENT). Beach/habitat-building flows and habitat maintenance flows may slow or somewhat reduce erosion of high terraces; however, the effects of such flows are not well known. Habitat maintenance flows under the Moderate and Modified Low Fluctuating and Seasonally Adjusted Steady Flow Alternatives would help to maintain sandbars (up to the river stage corresponding to 30,000 cfs) in certain locations, where they may protect high terraces from erosion by riverflows.

Some high terraces (mostly between the dam and RM 36) are subject to direct erosion from floodflows. This happens where there are no sandbars between the terrace and river (usually on the outside of a river bend) and, thus, no buffer against erosion. Therefore, an indicator of impacts to this type of terrace is the frequency of floods greater than 45,000 cfs: 1 in 40 years for the No Action and Maximum Powerplant Capacity Alternatives and 1 in 100 years for the other alternatives.

Debris Fans and Rapids

Changes in debris fans and rapids depend on tributary debris flows and discharge from the dam. While debris flows are independent of dam operations, the resulting debris fans historically have been reworked (boulders and smaller sediment moved downstream) by high flows, especially large floods (see chapter III, SEDIMENT).

Impacts to debris fans and rapids are considered here because of the concern that releases within powerplant capacity may not be large enough to move large boulders that constrict the channel and thus affect white-water boating safety. The relative capacity of the normal peak discharge to move boulders is used as an indicator of impacts to debris fans and rapids (see table IV-6). The percentages were calculated by dividing the square of the normal peak discharge in a minimum release year by the square of the 1983 peak discharge (92,600 cfs) and multiplying by 100. Beach/habitat-building flows were not considered because they would not occur every year, although such flows would remove larger material than could be removed by normal flows.

The relative numbers in table IV-6 show that maximum flows under all alternatives have much smaller capacity to move boulders than the predam annual floods, which were about the same magnitude as the 1983 flood. There probably is no measurable difference in capacity between alternatives with indicator values of 10 to 13 or between alternatives with values of 2 to 5. Further, the difference between these two groups probably is slight, but measurable.

Even with beach/habitat-building flows or habitat maintenance flows, none of the alternatives is expected to result in significant impacts to debris fans and rapids over the short term. Over the long term, new debris flows are expected to aggrade debris fans and further constrict rapids. Steady flow alternatives and the Interim Low Fluctuating Flow Alternative would have relatively less capacity to remove material from aggraded debris fans than other alternatives.

Lake Deltas

The size of deltas depends on the amount of total sediment transported to the lake. Delta elevation depends on average lake elevation, which varies with the amount of inflow and monthly release patterns. Delta crest elevation therefore can be used as an indicator of the delta surface elevation to compare impacts among alternatives. Beach/habitat-building flows and habitat maintenance flows would result in a 2- to 3-foot decrease in Lake Powell and a similar increase in Lake Mead over a 1- to 2-week period. These changes in lake levels are not expected to result in measurable impacts to sediment deposits in either lake.

Lake Powell. The rate of growth of Lake Powell deltas is independent of dam operations. Delta crest elevations are represented by the 20- and 50-year averages of projected monthly median lake elevations during April-August (3665 and 3662 feet above sea level). Annual release volumes are the same under all alternatives, and monthly releases volumes are the same under all but two—Seasonally Adjusted and Year-Round Steady Flow Alternatives. Delta crest elevations under these alternatives would be either the same as no action or as much as 2 feet lower (see table IV-6).

Elevations of the delta crests surveyed in 1986, after a period of high inflow and full reservoir, were higher than either the 20- or 50-year projected average lake elevations. Lake Powell deltas would continue to build downstream with new crests forming at lower elevations. Although Lake Powell tributaries would likely cut a relatively narrow channel through these deltas, most sediment would remain in place and become vegetated.

Lake Mead. Lake deltas consist of clay, silt, and sand. All sediment sizes must be considered when predicting impacts. The amount of clay and silt transported to the Lake Mead delta depends on upstream tributary supply and does not significantly vary among alternatives. However, the amount of sand transported to the delta over the short term does depend on the alternative.

Short-term sediment delivery from the Colorado River to Lake Mead would be greater under fluctuating than under steady flow alternatives. The differences between short-term delivery rates of the various alternatives are indicated by the difference in riverbed sand storage. Over the long term, the river will adjust its sediment load to match the tributary supply, regardless of the alternative implemented. The long-term sediment delivery rate to Lake Mead is expected to equal 12 million tons per year, of which about 3 million tons would be sand—equivalent to the long-term average supplied by the Paria River and the LCR.

The elevation of the delta crest in Lake Mead depends on lake elevation, which varies with the amount of inflow, as well as monthly release patterns at Hoover Dam. The indicator used to compare alternatives is the elevation of the delta crest, represented by the 20- and 50-year averages of projected monthly median lake elevations during July-October (1175 and 1167 feet above sea level). Annual release volumes are the same under all alternatives, and monthly release volumes are the same under all but two—Seasonally Adjusted and Year-Round Steady Flow Alternatives. Under these two alternatives, elevations of the delta crests would be either the same as no action or as much as 1 foot higher (see table IV-6).

Sediment deposition and erosion along the channel margins downstream from RM 236 in Lower Granite Gorge depend on Lake Mead water level and do not vary measurably among alternatives. Under all alternatives, deposition when lake levels are high is expected to be followed by erosion (including bank caving) during subsequent periods of lower lake levels.

Unrestricted Fluctuating Flows

No Action Alternative

Peak river stages associated with daily flow fluctuations under this alternative would have the potential to maintain high elevation sandbars (within normal peak river stage). However, the amount of riverbed sand would likely decline over time, and sandbars upstream of the LCR would experience net erosion.

Riverbed Sand. Probabilities of a net gain in riverbed sand are not high during a low water year and decrease with increases in annual release volumes (see appendix D). The probability of a net gain in sand storage (in the reach between the Paria River and LCR) is 50 percent at the end of 20 years and 41 percent at the end of 50 years. The sand balance downstream from the LCR would be expected to remain in a state of dynamic equilibrium. While some changes may occur from year to year, they would be expected to balance out over the long term.

Sandbars (Beaches and Backwaters). Sandbars would continue to be dynamic (cycles of deposition and erosion) under this alternative; they would change more rapidly as a result of floodflows. Some bars may be completely lost, and new bars may form. High elevation sandbars (separation bars above normal peak discharge) would be expected to erode during periods of normal operations. Low elevation sandbars (reattachment bars) downstream from Lees Ferry would be expected to aggrade in wide reaches of the canyon. During unanticipated floods, high elevation sandbars would be expected to aggrade in wide reaches. However, low elevation sandbars would be expected to erode. These predictions are based on analyses of historical data by Schmidt and Graf (1990) and Schmidt (1992).

Sandbars would continue to undergo cycles of deposition and erosion (see chapter III, SEDIMENT). Erosion would occur throughout the canyon due to the large daily changes in river stage and rapid decreases in stage upstream from the LCR. Seepage-induced erosion would increase during periods of lower minimum releases and reduced fluctuations, such as weekends and holidays.

The large daily changes in river stage would maintain existing active sandbar widths of unvegetated sand. Rapid increases in river stage would have little or no effect on sandbars. Sandbars in the Glen Canyon reach tend to exist in naturally protected areas but would likely erode at slow rates over the long term. Sandbars eroded from this reach would not be rebuilt.

Both the number and size of sandbars between Lees Ferry and the LCR would be expected to decline to some new equilibrium due to reduced riverbed sand. Generally, net erosion would decrease downstream, with the addition of sand from tributaries and reduced daily fluctuations.

Normal Operations.—The cycles of sandbar deposition and erosion would result in relatively large active widths of unvegetated sandbars. Daily discharge fluctuations from 1,000 to 24,000 cfs would result in river stage fluctuations ranging from about 7 feet in reach 5 to about 12 feet in reach 2. Active sandbar widths corresponding to these daily discharge fluctuations would range from 32 to 58 feet.

Over the course of a minimum release year, river stage fluctuations (potential sandbar heights above level of minimum flow) would range from about 10 feet in reach 5 to about 15 feet in reaches 2 and 6. Active sandbar width would range from 44 feet (reach 5) to 74 feet (reach 2). Sand would not deposit above the 31,500-cfs river stage during normal operations.

Eddy backwaters (open return-current channels) are dependent on the formation of reattachment bars. In the short term, the number and size of stable backwaters would vary with discharge (see FISH section in this chapter). Over the long term, backwaters would tend to fill with sediment and later re-form during the next flood release (an average of once in 40 years for floods 45,000 cfs and greater). Additional silt and clay delivered by tributary floods (typically during August-October) potentially could be deposited at elevations equivalent to the maximum flow.

Erosion due to natural forces such as runoff from local rainfall, wind, and tributary flash floods would continue (not influenced by dam operations). However, sandbars eroded by sudden natural events may eventually be rebuilt by river-supplied sand. Debris flows would cover some sandbars with cobbles and boulders.

Unanticipated Floods.—Large unanticipated floods of sediment-free water generally have a much more dramatic and immediate impact on sandbars than releases under normal operations. The magnitude and extent of the effects depend upon the magnitude and duration of the flood and prior storage of riverbed sand, and the effects on individual sandbars would vary greatly. Floods of short duration (days or weeks) may result in net deposition, but floods of long duration (months) or occurring too frequently would result in net erosion. If flood releases continue for several years in a row, as happened during 1983-86, sandbars of all types would be expected to erode upstream from the LCR.

High elevation sandbars deposited during flood releases would erode again under normal operations, with initially high rates of erosion becoming less with time. The greater the aggradation during floods, the greater the loss of sand during subsequent lower flows (Schmidt and Graf, 1990; Schmidt, 1992; Hazel et al., 1993; Kaplinski et al., 1994).

Some sandbars may be irretrievably lost during floods. In the Glen Canyon reach, sandbars eroded during floods would not be rebuilt. Loss of sand from some bars between Lees Ferry and the LCR also might be permanent; the likelihood of irretrievable loss of sand downstream from the LCR is much less.

High Terraces. High terraces in direct contact with the river would erode during floods greater than 45,000 cfs. On the basis of current information, such terraces exist mainly upstream of RM 36. Terraces on the outside of river bends would be most vulnerable.

Debris Fans and Rapids. Within the cycle of aggrading debris flows and eroding flood releases from Glen Canyon Dam, a new dynamic equilibrium would be established which would include some rapids that are narrower and steeper. Effects on channel width, vertical drop, and velocity at rapids would vary considerably from site to site. The channel could become narrow, and the elevation drop could increase to the point of adversely affecting river navigation (see RECREATION in this chapter).

The 1983 flood with a peak discharge of 92,600 cfs reworked many rapids in Grand Canyon. In the absence of large floods, limited capacity to reshape debris fans would exist because very high velocities are needed to widen the channel and decrease the elevation drop at major rapids (Kieffer, 1987; 1990). Under normal operations, capacity of the normal peak discharge to move boulders at debris fans would be reduced to about 12 percent, relative to the 1983 flood. Some debris fans aggraded by smaller debris flows would be reworked by the maximum 31,500-cfs fluctuating flows, which might have velocities high enough to move some boulders. Even with maximum riverflows of 31,500 cfs, it is likely that most of the largest material deposited by new debris flows would remain on the debris fans. Flood releases that can move larger boulders are expected to occur an average of once in 40 years.

Lake Deltas. The profile shape and position of sediment delta crests are controlled primarily by changes in lake surface elevation and the amount of sediment transported into the lake.

Lake Powell.—The quantity of sediment flowing into the Lake Powell area is independent of Glen Canyon Dam operations. When the lake elevation is high, sediment would be deposited in the upstream parts of the deltas. When lake elevation is low, the inflowing sediment would be carried much farther into the lake. Lake Powell elevations would fluctuate seasonally (typically 15 to 30 feet) and tend to be lowest from February to April and highest from June to August.

Over the short and long term, delta crest elevations would tend to be lower than their present levels and would approximately equal the average of April through August median lake elevations. These elevations are projected to be 3665 and 3662 feet above sea level over the next 20 and 50 years. Lake Powell tributaries would cut relatively narrow channels across the deltas and transport some sediment downstream. However, most of the sediment deposits would tend to remain in place and would become vegetated.

Sediment depositing in Lake Powell may contain trace metals and organic pollutants. However, the sediment chemistry and the potential for these pollutants to be released into the lake are unknown (see the discussion of water quality in the WATER section of this chapter).

Lake Mead.—Short-term sediment delivery rates to the Colorado River delta in Lake Mead under this alternative would be among the highest of any alternative. Over the long term, the average rate of sediment accumulation in Lake Mead would equal the average total sediment load of Grand Canyon tributaries (approximately 12 million tons per year).

Seasonal and annual changes in lake elevation mainly depend on changes in storage of Lakes Powell and Mead. Lake elevations would fluctuate seasonally (typically 10 to 12 feet) and would tend to be lowest in summer and highest in winter. Most sediment would enter Lake Mead during the summer and fall (July through October). Delta crest elevation would be about the same as present levels and would approximately equal the average of July through October median lake elevations. These lake elevations are projected to be 1175 and 1167 feet above sea level over the next 20 and 50 years, respectively.

Maximum Powerplant Capacity Alternative

Under this alternative, impacts on all sediment resources would be essentially the same as those under the No Action Alternative. Maximum releases higher than permitted under no action (31,500 cfs) would be possible when Lake Powell elevation is at or above 3641 feet, combined with a high demand for electrical power. These higher maximum releases would result in a negligible decrease in the quantities of **riverbed sand** storage in either the short or long term compared to no action.

Corresponding increases in river stage between 31,500 cfs and 33,200 cfs would be about 0.5 foot. This would result in a negligible increase in active width and height of **sandbars**, compared to the No Action Alternative (see appendix D).

Impacts to **high terraces, debris fans and rapids**, and to **lake deltas** would be essentially the same as those under no action.

Restricted Fluctuating Flows

Impacts to sediment resources under the High, Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives are described in this section. An overview of common impacts of these alternatives is presented first, followed by specific details about individual alternatives.

Riverbed Sand

More riverbed sand would be stored under the restricted fluctuating flow alternatives than under either the No Action or Maximum Powerplant Capacity Alternatives but less than under the steady flow alternatives. Storage of riverbed sand increases as the allowable daily fluctuation range becomes more restricted. Net accumulation would tend to be greater in wider reaches, where velocities are relatively low, than in narrower reaches. Because of flood frequency reduction measures, unanticipated floods would likely result in increased deposition relative to the floods under the No Action or Maximum Powerplant Capacity Alternatives.

Sandbars (Beaches and Backwaters)

Sandbars would be dynamic (cycles of erosion and deposition) but more stable than under the No Action or Maximum Powerplant Capacity Alternatives. Sandbar heights would be less, but the amount of riverbed sand available for deposition would increase over time. Sandbar heights and active widths would be greater than under steady flow conditions, except the Seasonally Adjusted Steady Flow Alternative with habitat maintenance flows. On the basis of maximum flows during minimum release years, the rate of filling of backwater return-current channels with sand and silt between floods or special high releases would be about the same as under no action. An exception is the Interim Fluctuating Flow Alternative, under which backwaters would be expected to fill at the greater rates expected under the steady flow alternatives. With higher maximum flows during the tributary flood season, restricted fluctuating flow alternatives are more likely than steady flow alternatives to result in deposition of new silt and clay in the eddies.

Beach/habitat-building flows would have the potential to rebuild high elevation sandbars and re-form backwater return-current channels. Sand deposition may bury existing vegetation at some locations. Habitat maintenance flows under the Moderate and Modified Low Fluctuating Flow Alternatives also would rebuild sandbars and re-form return-current channels.

Releases resulting from emergency exception criteria are assumed typically to be of small magnitude and short duration or infrequent and of short duration, with negligible effects.

High Terraces

Erosion of high terraces in direct contact with the river would be less than under no action because the frequency of flood-caused erosion would average only 1 in 100 years.

Debris Fans and Rapids

Impacts to debris fans and rapids under the fluctuating flow alternatives would be similar to those described under the No Action Alternative. In the absence of large floods, there would be limited capacity to reshape debris fans because very high velocities are needed to widen the channel and decrease the elevation drop at major rapids (Kieffer, 1987; 1990).

Channel width, vertical drop, and velocity at some rapids associated with new debris flows would be affected. The channel width would narrow, and the elevation drop would increase to the point of adversely affecting river navigation. The capacity to move boulders is assumed to be proportional to the normal peak discharge squared relative to the 1983 peak discharge (92,600 cfs) squared. The capacity of the normal peak discharge to move boulders at debris fans during minimum release years would be about 12 to 5 percent of the capacity of the 1983 peak discharge as shown below.

Alternative	Normal peak discharge (cfs)	Capacity to move boulders relative to 1983 flood (percent)
High fluctuating flow	31,500	12
Moderate fluctuating flow	30,000	10
Modified low fluctuating flow	30,000	10
Interim low fluctuating flow	20,000	5

Lake Deltas

Lake delta crest elevations under the restricted fluctuating flow alternatives would be the same as elevations under the No Action Alternative because annual and monthly lake elevations would be the same.

The Lake Mead delta would continue to increase in size and progress downstream toward Hoover Dam. Over the short term, the amount of sand and gravel reaching Lake Mead would be less under the restricted fluctuating flow alternatives than under the No Action or Maximum Powerplant Capacity Alternatives. Over the long term, the average rate of total sediment accumulation in Lake Mead would be equal to the average total sediment load supplied by Grand Canyon tributaries.

High Fluctuating Flow Alternative

Impacts to sediment resources under this alternative would be similar to those described under the No Action Alternative. However, there would be differences primarily due to the restrictions in the range of daily flow fluctuations. More **riverbed sand** would be stored, but sandbar heights and active widths would remain about the same as no action.

The probability of a net gain in sand storage (in the reach between the Paria River and LCR) is 53 percent at the end of 20 years and 45 percent at the end of 50 years. The relatively high percentage of days with maximum hourly flows greater than 20,000 cfs would likely result in little, if any, net gain in riverbed sand.

Sandbars would continue to be dynamic with large active widths. Seepage-induced erosion would continue, especially during weekends and holidays when minimum flows would be lower.

Daily discharge fluctuations from 3,000 to 23,000 cfs would result in river stage fluctuations from about 7 feet in reaches 5 and 11 to about 11 feet in reaches 2 and 6. Active sandbar widths corresponding to these daily fluctuations would range from 30 to 51 feet. Over the course of a minimum release year, potential sandbar height above the level of minimum flow would range from about 7 feet in reach 5 to about 11 feet in reaches 2, 6, and 9, with active sandbar width ranging from 33 to 53 feet (see appendix D). Sand would not deposit above the river stage corresponding to about 25,500 cfs during normal operations.

When Lake Powell storage is 19 maf or less, beach/habitat-building flows of 41,500 cfs would be expected to aggrade sandbars in all major eddies to elevations 3 to 4 feet higher than the normal peak river stage (see appendix D).

Moderate Fluctuating Flow Alternative

More **riverbed sand** would be stored under this alternative than under the No Action, Maximum Powerplant Capacity, or High Fluctuating Flow Alternatives. Peak river stages would have less capacity to rebuild eroded sandbars, but seepage-induced erosion would be reduced.

The probability of a net gain in sand storage (in the reach between the Paria River and LCR) is 61 percent at the end of 20 years and 70 percent at the end of 50 years. Effects of habitat maintenance flows are included; they increase the annual sand transport capacity by about 117,000 tons and reduce the probability of net increase in riverbed sand by about 12 percent in years when they occur.

With habitat maintenance flows, **sandbars** would be dynamic, but less subject to long-term erosion than under the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives. Seepage-induced erosion would be less because of the reduced daily range in fluctuations, reduced down ramp rates, and because minimum flow criteria would be constant within each month (weekend minimum flows would not be less than allowable weekday minimum flows). Also, the shape and size of the recirculation zones would be more stable, but they would tend to gradually fill with sediment and become vegetated. Effects of wave-induced erosion would be distributed within a narrower range of fluctuating river stage than under the No Action or High Fluctuating Flow Alternatives.

Daily discharge fluctuations from 5,000 to 13,200 cfs would result in river stage fluctuations ranging from about 3 feet in reaches 5 and 11 to about 5 feet in reaches 2, 3, and 6. Active sandbar widths corresponding to these daily fluctuations would range from 10 to 21 feet. Over the course of a minimum release year, normal river stage fluctuations would range from about 6 feet in reach 5 to about 10 feet in reach 6, with active sandbar width ranging from 28 to 47 feet. With habitat maintenance flows, potential sandbar heights would be about 2 to 4 feet higher, and active widths about 13 to 19 feet wider. Beach/habitat-building flows of 40,000 cfs would be expected to aggrade sandbars in all major eddies to elevations 3 to 5 feet higher than the river stage of habitat maintenance flows (appendix D).

Modified Low Fluctuating Flow Alternative

More **riverbed sand** would be stored under this alternative than under the No Action, Maximum Powerplant Capacity, and High or Moderate Fluctuating Flow Alternatives. With habitat maintenance flows, peak river stages would have the capability to rebuild eroded sandbars. Seepage-induced erosion generally would be reduced; however, some would still occur during weekends and holidays due to lower minimum flows and reduced fluctuations.

The probability of a net gain in sand storage (in the reach between the Paria River and LCR) is 64 percent at the end of 20 years and 73 percent at the end of 50 years. Effects of habitat maintenance flows are included. They increase the annual sand transport capacity by about 118,000 tons and reduce the probability of net gain in riverbed sand by about 11 percent in years when they occur.

With habitat maintenance flows, **sandbars** would tend to be dynamic on an annual basis, but otherwise would be more stable and exist at lower elevations than under the other fluctuating flow alternatives. The shape and size of the recirculation zones would be similar to the other fluctuating flow alternatives.

With maximum down ramp rates of 1,500 cfs per hour, seepage-induced erosion would still occur but would be greatly reduced. Seepage-induced erosion would be most noticeable during periods of prolonged low releases, such as weekends and holidays. Maximum up ramps of 4,000 cfs would have little or no effect on sandbars. Effects of wave-induced erosion would be distributed within a narrower range of fluctuating river stage than under other fluctuating flow alternatives.

Daily discharge fluctuations from 5,000 to 10,000 cfs would result in river stage fluctuations ranging from about 1 foot in reach 11 to about

3 feet in reaches 1, 2, 3, and 6. Active sandbar widths corresponding to these daily discharge fluctuations would range from 1 to 12 feet. Over the course of a minimum release year, normal stage fluctuations would range from about 6 feet in reaches 4 and 5 to about 9 feet in reach 6, with active sandbar width ranging from 24 to 41 feet. With habitat maintenance flows, potential sandbar heights would be about 3 to 5 feet higher, and active widths about 17 to 24 feet wider.

Beach/habitat-building flows of 40,000 cfs would be expected to aggrade sandbars in all major eddies to elevations 3 to 5 feet higher than the river stage of habitat maintenance flows.

Normal flows during low and moderate release years have less capacity to reshape debris fans under this alternative than under no action. With habitat maintenance flows, this alternative's capacity to move boulders would be approximately equal to that under no action. Generally, the constrictions at rapids would remain the same or become narrower and steeper when new debris flows occur.

Interim Low Fluctuating Flow Alternative

More **riverbed sand** would be stored under this alternative than under the No Action, Maximum Powerplant Capacity, High, Moderate, or Modified Low Fluctuating Flow Alternatives. Peak river stages would have limited capability to rebuild eroded sandbars, and seepage-induced erosion would be reduced. However, some seepage-induced erosion would still occur during weekends and holidays due to lower minimum flows and reduced fluctuations.

The probability of a net gain in sand storage (in the reach between the Paria River and LCR) is 69 percent at the end of 20 years and 76 percent at the end of 50 years.

Sandbars would tend to be more stable and exist at lower elevations than under the other fluctuating flow alternatives. The shape and size of the recirculation zones would be more stable than under the other fluctuating flow alternatives but would more rapidly fill with sediment and become vegetated.

With maximum down ramp rates of 1,500 cfs per hour, seepage-induced erosion would still occur but would be greatly reduced. Seepage-induced erosion would be most noticeable during periods of prolonged low discharge releases, such as weekends and holidays. Effects of wave-induced erosion would be distributed within a narrower range of fluctuating river stage than under other fluctuating flow alternatives.

Daily discharge fluctuations from 5,000 to 10,000 cfs would result in river stage fluctuations ranging from about 1 foot in reach 11 to about 3 feet in reaches 1, 2, 3, and 6. Active sandbar widths corresponding to these daily discharge fluctuations would range from 1 to 12 feet (see appendix D).

Over the course of a minimum release year, river stage fluctuations would range from about 6 feet in reaches 4 and 5 to about 9 feet in reach 6, with active sandbar width ranging from 24 to 41 feet. Potential sandbar heights above the minimum river stage would range from 6 to 9 feet. Sand would not deposit above the 20,000-cfs river stage during a minimum release year.

Beach/habitat-building flows of 40,000 cfs would be expected to aggrade sandbars in all major eddies to elevations 3 to 5 feet higher than the normal peak river stage (see appendix D).

Flows during low and moderate release years have less capacity to reshape debris fans under this alternative than under other fluctuating flow alternatives. Generally, the constrictions at rapids would remain the same or become narrower and steeper when new debris flows occur.

Steady Flows

Impacts to sediment resources under the Existing Monthly Volume, Seasonally Adjusted, and Year-Round Steady Flow Alternatives are described in this section. An overview of common impacts from these alternatives is presented first, followed by specific details about individual alternatives.

Riverbed Sand

When compared to other alternatives, steady flow alternatives would store the greatest amounts of riverbed sand. Larger accumulations of riverbed sand would mean greater potential for bar-building during high flows. Annual peak river stages would vary under the steady flow alternatives but would be less than those under the other alternatives, resulting in sandbars being rebuilt at relatively low elevations. However, seepage-induced erosion would no longer occur, and other erosion rates generally would be low.

Between Lees Ferry and the LCR, the river would accumulate sand and gravel over time. Net accumulation would tend to be greater in wider reaches, where velocities are relatively low, than in narrower reaches. The sand balance in the reach between the LCR and Diamond Creek would be expected to remain in a state of dynamic equilibrium.

Sandbars (Beaches and Backwaters)

Sandbars would tend to be more stable and at lower elevations under the Existing Monthly Volume and Year-Round Steady Flow Alternatives than under any of the fluctuating flow alternatives. Under the Seasonally Adjusted Steady Flow Alternative, sandbars would be dynamic (due to habitat maintenance flows) but more stable than under the No Action Alternative. Sandbar heights would be about the same as under no action.

Sandbars would be subject to seasonal cycles of erosion and deposition due to seasonal variations in releases. Sand would tend to deposit on bars at slopes approaching 26 degrees during high river stage periods. The effects of allowable daily changes (plus or minus 1,000 cfs) for power system load changes would be negligible. Because of wave transformation and changes in channel width, the variation would be about plus or minus 500 cfs at Lees Ferry (plus or minus 0.2-foot river stage change) and would disappear from the hydrograph at some point between Lees Ferry and the LCR.

Annual peak discharges under steady flow alternatives would have relatively little capability to rebuild eroded sandbars. Erosion caused by riverflow would be minimal, and seepage-induced erosion would no longer occur. The rate at which backwaters in return-current channels would fill with sand and silt between floods or special high releases would be greater than under fluctuating flows. With lower maximum flows during the tributary flood season, the alternatives in this group are less likely than the fluctuating flow alternatives to result in deposition of new silt and clay in the eddies.

Beach/habitat-building flows would have the potential to rebuild high elevation sandbars and would also re-form backwater return-current channels. Habitat maintenance flows under the Seasonally Adjusted Steady Flow Alternative also would rebuild sandbars and re-form return-current channels.

Unanticipated floods would have impacts similar to those under no action. However, because of flood frequency reduction measures, unanticipated floods would likely result in net deposition of sandbars. More sand would be available for transport and deposition during floods because of increased capacity to store sand during normal operations. High elevation sandbars would be expected to aggrade in wide reaches; low elevation bars would be expected to erode.

Releases resulting from emergency exception criteria are assumed typically to be of small magnitude and short duration or infrequent and of short duration, with negligible effects.

High Terraces

High terraces in direct contact with the river would erode less than under no action because the frequency of flood-caused erosion would average only 1 in 100 years.

Debris Fans and Rapids

Impacts to debris fans and rapids under the steady flow alternatives would be greater than those under the fluctuating flow alternatives. Generally, the constrictions at rapids would remain the same or become narrower and steeper when new debris flows occur.

Annual peak discharges under the Existing Monthly Volume and Year-Round Steady Flow Alternatives have the least capacity to remove sediment from debris fans, and some rapids would become even more constricted. The capacity of the normal peak discharge to move boulders on debris fans during minimum release years would be about 3 percent of the capacity of the 1983 peak discharge. With habitat maintenance flows, the Seasonally Adjusted Steady Flow Alternative would have a relatively higher capacity to move boulders. Normal peak discharges and capacity to move boulders for the steady flow alternatives are listed below.

Steady flow alternative	Normal peak discharge (cfs)	Capacity to move boulders relative to 1983 flood (percent)
Existing monthly volume	16,300	3
Seasonally adjusted	30,000	10
Year-round	11,900	2

Lake Deltas

Impacts to lake deltas under the steady flow alternatives would be the same as or similar to those under no action because annual lake elevations would be the same. Monthly lake elevations under the Existing Monthly Volume Steady Flow Alternative would be the same as no action; monthly lake elevations under the other two steady flow alternatives would be different.

Lake Powell. The average of the median monthly water surface elevations for Lake Powell for April through August over the next 20 and 50 years are shown below.

Steady flow alternative	Lake Powell elevations (feet)	
	20 years	50 years
Existing monthly volume	3665	3662
Seasonally adjusted	3664	3660
Year-round	3664	3660

Lake Mead. The average of the median monthly Lake Mead water surface elevations for July through October projected over the next 20 and 50 years are shown below.

Steady flow alternative	Lake Mead elevations (feet)	
	20 years	50 years
Existing monthly volume	1175	1167
Seasonally adjusted	1176	1168
Year-round	1176	1168

Over the short term, the amount of sand and gravel reaching Lake Mead would be less under the steady flow alternatives than under any of the fluctuating flow alternatives. Over the long term, the average rate of total sediment accumulation in Lake Mead would be equal to the average total sediment load supplied by Grand Canyon tributaries (approximately 12 million tons per year).

Existing Monthly Volume Steady Flow Alternative

The amount of **riverbed sand** transported under this alternative would be less than under the fluctuating flow alternatives and the Seasonally Adjusted Steady Flow Alternative. Conversely, the amount of sand and gravel stored as riverbed material within the channel pools and eddies would be greater than under those alternatives.

The probability of a net gain in sand storage (in the reach between the Paria River and LCR) is 71 percent at the end of 20 years and 82 percent at the end of 50 years.

Sandbars would tend to be more stable and exist at lower elevations under this alternative than under all but the Year-Round and Seasonally Adjusted Steady Flow Alternatives. The shape and size of the recirculation zones also would be more stable, but would tend to fill more rapidly with sediment and become vegetated.

The channel would aggrade at a higher rate between the Paria River and the LCR than under all of the fluctuating flow alternatives. With greater amounts of stored sand, there is greater potential for aggradation of sandbars and less potential for net degradation of sandbars during spills.

Over the course of a minimum release year, monthly changes in river stage would range from about 3 to 5 feet, with active sandbar width ranging from about 10 to 19 feet. Sandbar heights above the minimum river stage would range from 3 to 5 feet. Sand would not deposit above the river stage corresponding to 16,300 cfs during a minimum release year (see appendix D).

Beach/habitat-building flows of 26,300 cfs would be expected to aggrade sandbars in all major eddies to elevations 3 to 5 feet higher than the river stage of habitat maintenance flows if there is adequate sand in the river channel. Sand deposition may bury existing vegetation at some locations.

During low and moderate release years, flows would have less capacity to reshape **debris fans** than under all but the Year-Round Steady Flow Alternative. The constrictions at **rapids** would remain the same or become narrower and steeper when new debris flows occur.

Lake Powell elevations would fluctuate seasonally (typically 15 to 30 feet) and tend to be lowest from February to April and highest from June to August. Lake Mead elevations would fluctuate less (typically 10 to 12 feet) and would tend to be lowest in summer and highest in winter.

Seasonally Adjusted Steady Flow Alternative

During normal operations, **riverbed sand** would be stored at lower elevations within the eddies than under the fluctuating flow alternatives because of the lower discharge and river stage.

The probability of a net gain in sand storage in the reach between the Paria River and LCR is 71 percent at the end of 20 years and 82 percent at the end of 50 years. Effects of habitat maintenance flows are included. They increase the annual sand transport capacity by about 124,000 tons and reduce the probability of net gain in riverbed sand by about 11 percent in years when they occur.

Over the course of a minimum release year, seasonal changes in river stage would range from about 4 feet to about 7 feet, with active **sandbar** width ranging from 16 to 29 feet. With habitat maintenance flows, potential sandbar heights would be about 4 to 6 feet higher, and active widths about 21 to 31 feet wider (see appendix D).

Beach/habitat-building flows of 40,000 cfs under this alternative would be expected to aggrade sandbars in all major eddies to elevations 3 to 5 feet higher than the normal maximum river stage, if there is adequate sand supply in the river channel. Sand deposition may bury existing vegetation at some locations.

During low and moderate release years, normal flows under this alternative would have less capacity to reshape **debris fans** than those under all fluctuating flow alternatives. With habitat maintenance flows, this alternative would have a capacity to move boulders approximately equal to that under no action. Generally, the constrictions at **rapids** would remain the same or become narrower and steeper at some sites when new debris flows occur.

Lake Powell elevations would fluctuate seasonally and tend to be 1 to 4 feet higher than under no action from December through May and 1 to 2 feet lower from June through August. Lake Mead elevations would typically be 1 to 2 feet lower from January through April and 1 to 2 feet higher from June through August than lake elevations under no action.

Year-Round Steady Flow Alternative

Compared to all other alternatives, flows under this alternative would transport the least amount of **riverbed sand** but would store the greatest amount of sand and gravel within the main channel and eddies. Larger accumulations of sand in the river would mean greater potential for bar-building during high flows. During normal operations, sand would be stored at lower elevations within the eddies since this alternative has the lowest discharge and river stage.

The probability of a net gain in sand storage in the reach between the Paria River and LCR is 74 percent at the end of 20 years and 100 percent at the end of 50 years.

Sandbars would tend to be more stable and exist at lower elevations under this alternative than under any other alternative. The shape and size of the recirculation zones would be more stable and would more rapidly fill with sediment and become vegetated than under the other alternatives. Steady flows under this alternative would expose the greatest amount of sandbar area above normal high water. However, most reattachment bars would be submerged much of the time.

Over the course of a minimum release year, river stages would fluctuate less than 1 foot, with virtually no active widths. Sandbar heights above the minimum river stage would range from 0 to 1 foot. Sand would not deposit above the river stage corresponding to 11,900 cfs during a minimum release year.

Beach/habitat-building flows of 21,900 cfs under this alternative would be expected to aggrade sandbars in all major eddies to elevations 4 to 6 feet higher than the normal peak river stage.

Flows under this alternative have the least capacity to remove sediment from **debris fans**. Debris fans would aggrade, and **rapids** would become steeper and more constricted under this alternative compared to conditions under no action.

Lake Powell elevations would fluctuate seasonally and tend to be 1 to 2 feet lower than no action elevations from April through July. Lake Mead elevations would typically be 1 to 2 feet higher during April, May, and June than lake elevations under no action.

FISH

Issue:

How do dam operations affect FISH—their food base, life cycles, habitat, and ability to spawn?

Indicators:

Abundance of *Cladophora* and associated diatoms for **aquatic food base**
Reproduction, recruitment, and growth of **native fish**
Reproduction, recruitment, and growth of **non-native warmwater and coolwater fish**
Level of **interactions between native and non-native fish**

The focus of this impact assessment is on native fish, non-native warmwater and coolwater fish, interactions between native and non-native fish, and trout. The native fish considered in this section include the humpback chub, razorback sucker (both federally endangered species), flannelmouth sucker (being considered for listing as a federally endangered species), bluehead sucker, and speckled dace.

Each alternative analyzed in this section results in physical effects to the aquatic environment that alter fish habitats in Glen and Grand Canyons. These effects are direct if they alter conditions necessary for the growth, survival, or health of a population. For example, mainstem water temperature has a direct effect on the ability of warmwater native fish to successfully reproduce or for young to survive. Effects are indirect if they influence one component of the aquatic community that then affects another. Reliable minimum flows of an alternative may directly influence *Cladophora* and, in turn, indirectly affect fish because of their influence on the availability of food resources.

Likewise, effects may be short-term or long-term. Short-term effects influence only 1 or 2 reproductive years. Long-term effects extend up to or beyond the generation time of an individual (from hatching through the reproductive life of that individual). These effects may be retrievable or reversible. For example, loss of 1 year's reproduction for a long-lived fish may be made up in a subsequent year when conditions are favorable. On the other hand, the same kinds of effects may be irretrievable or irreversible if they occur consistently.

Analysis Methods

Both biological productivity and physical characteristics of the environment (temperature, reliable flow, turbidity, etc.) determine the limits of fish development. Therefore, it is necessary to assess the biological productivity of the aquatic food base, as well as the environment's physical characteristics, when evaluating impacts to fish under each alternative.

Aquatic Food Base

The aquatic food base in Glen and Grand Canyons is the indicator for growth and condition of the system's fish. *Cladophora* production in the Glen Canyon reach provides an important component of the food base for downstream reaches and responds to reliable inundation in a fashion similar to aquatic benthos in downstream reaches. Thus, the productive band of shoreline (wetted perimeter) that can be occupied by this important alga in the Glen Canyon reach reflects the condition of the aquatic food base as a whole. The reliable wetted perimeter, in turn, is determined by the minimum reliable river stage (flow) under each alternative.

For purposes of the analysis, the river's productive capacity under each alternative can be estimated only tenuously. But, using no action conditions as a baseline, comparison of zones that would reliably experience less than 12 hours of continuous exposure (as measured in vertical feet of stage and wetted perimeter at a site near Lees Ferry) is assumed to index the proportional differences between no action and the other alternatives. The minimum reliable stage noted near Lees Ferry under fluctuating flows may be relatively higher downstream, particularly below the LCR, because of a phenomenon known as wave transformation (chapter III, WATER). As waves produced by fluctuating releases move downstream, water volume tends to decrease in the peaks (lowering maximum river stage) and increase in the troughs (raising minimum river stage).

Native Fish

The analysis of effects on fish is based on their basic life requirements and addresses:

- Direct sources of mortality
- Potential to reproduce and recruit (survive to adulthood)
- Potential for growth

Alternatives are analyzed with regard to mainstem water temperature and tributary access for reproduction, food base and stable nearshore and backwater environments for recruitment and growth, flood frequency reduction measures, and beach/habitat-building flows.

Reproduction of native fish requires warm water temperatures. Recruitment (the ability of these fish to survive to the next life stage) depends on warm tributaries and the processes that develop and maintain backwaters and shallow nearshore areas capable of warming separately from the main channel. Fish growth is necessary to achieve recruitment. The rate of growth is determined by water temperature and food base quality and availability. Necessary habitat conditions for each life stage must also be available (for example, young-of-year fish require low velocity areas such as backwaters and nearshore habitats).

Tributary confluences and the portion of the tributary immediately upstream have slower current or become ponded with increased river stage. Larval fish that rear in these areas may be able to avoid or delay entering the harsher mainstem conditions. Therefore, river stage can affect recruitment and growth.

Many humpback chub have been collected within an 8.5-mile reach approximately centered on the LCR (Valdez, Masslich, and Leibfried, 1992). Larvae or young-of-year humpback chub are transported out of that tributary (RM 61.4) into the mainstem (Angradi et al., 1992). Therefore, reach 4 (lower Marble Canyon beginning at RM 36) and reach 5 (Furnace Flats ending at RM 77) represent important humpback chub habitats and were selected for analysis.

Non-Native Warmwater and Coolwater Fish

Non-native warmwater and coolwater fish requirements are nearly identical to those of native fish. Evaluation criteria for non-native warmwater and coolwater fish include the aquatic food base, mainstem and tributary reproduction, and mainstem recruitment and growth.

Interactions Between Native and Non-Native Fish

Alternatives were qualitatively evaluated for potential interactions (competition and/or predation) between native and non-native fish. This evaluation focused on each alternative's effects on nearshore and backwater habitats used by both native and non-native fish.

Trout

Alternatives were analyzed with regard to adult stranding mortality, redd success in the mainstem, and tributary access for spawning in Grand Canyon.

Summary of Impacts: Fish

The impacts of the alternatives on fish are summarized in table IV-8.

Aquatic Food Base

Figure IV-12 compares impacts to the aquatic food base, using reliable wetted perimeter as the indicator of effects. Wetted perimeter, hence the aquatic food base, tends to increase as the minimum reliable discharge increases.

Table IV-9 shows river stage and wetted perimeter associated with reliable minimum flows at three sites below Glen Canyon Dam: a point just below Glen Canyon Dam, a point in a shallow riffle area downstream of the dam, and a point at Lees Ferry. The difference between change in wetted perimeter and stage of pools and riffles illustrates the greater productive capacity of shallow, cobble riffles. Therefore, more surface area for colonization by benthic algae and invertebrates is available along wide cobble benches than along steep canyon walls.

Native Fish

None of the alternatives change the temperature of the water released from Glen Canyon Dam. This single fact constrains warmwater fish reproduction in the main channel and limits the likelihood that young native fish would grow to reproductive size. This condition emphasizes the importance of warm tributaries, return-current channel backwaters, and shallow nearshore areas as recruitment sites under current conditions (Maddux et al., 1987; Angradi et al., 1992; Valdez, Masslich, and Leibfried, 1992).

Backwaters and nearshore areas would warm somewhat during warm months under all alternatives, but would warm more under the steady flow alternatives. By introducing cold main channel water, daily fluctuations under some alternatives would destabilize and limit warming of backwater and nearshore areas used as nursery habitat by young fish.

Because of limited warming of the main channel, backwaters, and nearshore areas, effects on mainstem reproduction for native fish are nearly identical under all alternatives, including no action. No alternative directly addresses modifying the temperature of the main channel (though further study of selective withdrawal is a common element). Thus, egg and larval survival in the main channel is unlikely. An insignificant increase in reproduction may occur under the steady flow alternatives in nearshore environments; however, warmwater fish would continue to rely on tributaries for reproduction under all alternatives.

Table IV-8.—Summary of anticipated impacts on FISH by alternative

FISH	No Action	Maximum Power-plant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Aquatic food base	Limited by reliable wetted perimeter	Same as no action	Minor increase	Moderate increase	Potentially major increase	Potentially major increase	Major increase	Major increase	Major increase
Native fish	Stable to declining	Same as no action	Same as no action	Same as no action	Potential minor increase	Potential minor increase	Uncertain[1] potential minor increase	Uncertain[1] potential major increase	Uncertain[2] potential minor increase
Mainstem reproduction[2]	None	None	None	None	None	Insignificant	Insignificant	Insignificant	Insignificant
Tributary reproduction	Access temporarily limited at low flows	Same as no action	Same as no action	Access not limited	Access not limited	Access not limited	Access not limited	Access not limited	Access not limited
Mainstem recruitment and growth	Limited by temperature and daily fluctuations in habitats	Same as no action	Temperature limited	Temperature limited	Temperature limited, more stable nearshore habitats, summer low flows limit backwaters	Temperature limited, more stable nearshore habitats, summer minimums limit backwaters	Temperature limited, stable nearshore habitats, summer minimums limit backwaters	Temperature limited, stable backwaters and nearshore habitats	Temperature limited, nearshore habitats stabilized, backwaters likely inundated
Non-native warm-water and cool-water fish	Stable to declining	Same as no action	Same as no action	Same as no action	Potential minor increase	Potential minor increase	Potential minor increase	Potential minor increase	Potential minor increase
	Mainstem reproduction, tributary reproduction, and mainstem recruitment and growth impacts are identical to native fish under all alternatives.								
Interactions between native and non-native fish	Some predation and competition by non-natives	Same as no action	Same as no action	Same as no action	Potential minor increase in warm, stable microhabitats	Potenial minor increase in warm, stable microhabitats	Potential moderate increase in warm, stable microhabitats	Potential moderate increase in warm, stable microhabitats	Potential moderate increase in warm, stable microhabitats
Trout[3]	Stocking-dependent	Same as no action	Same as no action	Increased growth potential, stocking-dependent	Increased growth potential, stocking-dependent	Increased growth potential, stocking-dependent	Increased growth potential, possibly self-sustaining	Increased growth potential, possibly self-sustaining	Increased growth potential, possibly self-sustaining
Adult stranding mortality	11 major stranding pools	Same as no action	Stranding pools reduced 20%	Stranding pools reduced > 20%	Stranding pools reduced > 20%	Stranding pools reduced > 20%	Stranding pools reduced > 55%	Stranding pools reduced > 55%	Stranding pools reduced > 55%
Glen Canyon reproduction and recruitment	90% of redd sites affected	Same as no action	60-90% of redd sites affected	83% of redd sites affected	83% of redd sites affected	83% of redd sites affected	Redd sites unaffected, stable fry habitat	Redd sites unaffected, stable fry habitat	Redd sites unaffected, stable fry habitat
Downstream reproduction and recruitment	Adequate tributary access, limited by minimum flows	Same as no action	Increase in reliable access	Increase in reliable access	Increase in reliable access	Increase in reliable access	Increase in reliable access	Increase in reliable access	Increase in reliable access

[1] There is uncertainty among resource scientists regarding the significance of response of native fish to steady releases because of the potential for interaction with non-native fish.

[2] While some habitat components used by native and warmwater non-native fish would improve, cold mainstem water temperatures would continue to restrict spawning to suitable tributaries under all alternatives.

[3] Growth and condition of trout would parallel effects described for the aquatic food base under each alternative. Growth and condition could be compromised by fish health problems under any alternative. The type of potential problems or their cause cannot be predicted.

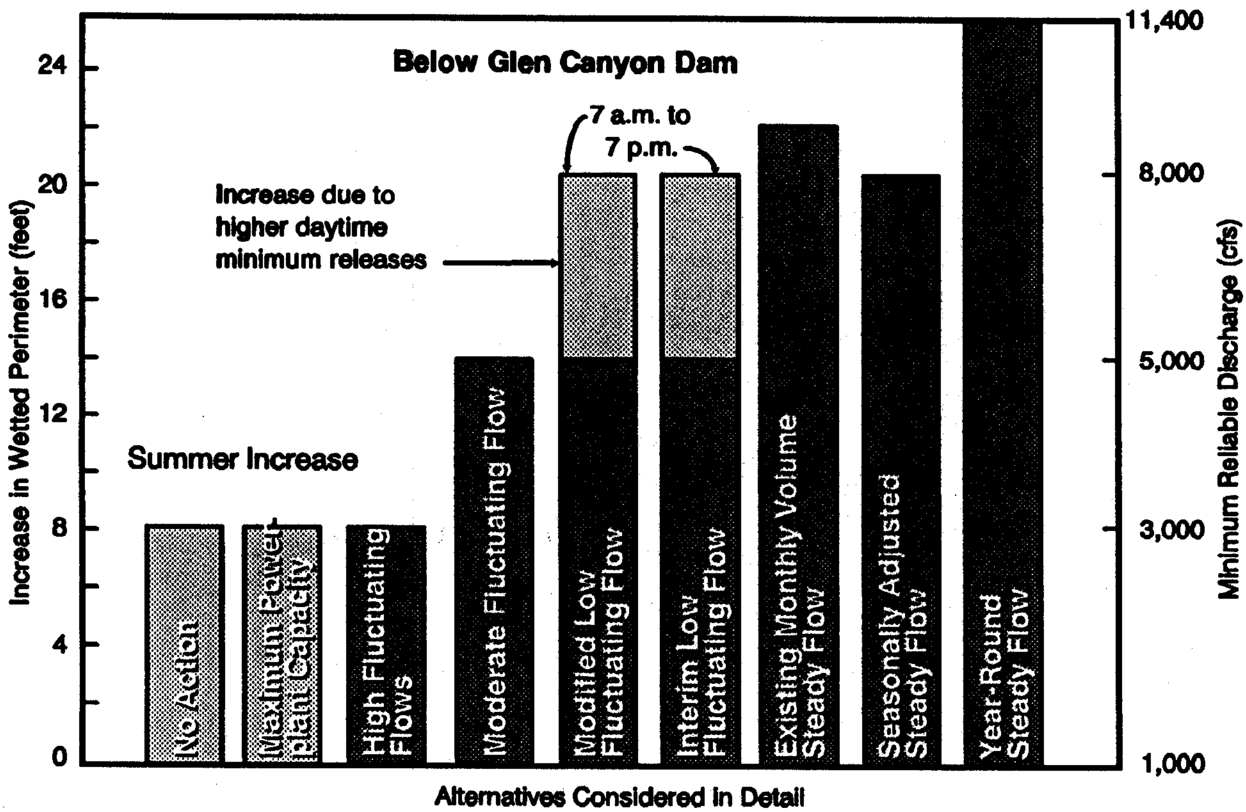


Figure IV-12.—Comparison of impacts to the aquatic food base by alternative, using reliable wetted perimeter near Glen Canyon Dam as the indicator of effects.

Access to tributaries may be limited under those alternatives with minimum releases of less than 5,000 cfs (some fluctuating flow alternatives). Access limitations, if any, would be temporary, with access likely available during some part of the day. Access to tributaries would not be limited under alternatives with minimum releases of 5,000 cfs or more (Arizona Game and Fish Department, unpublished data).

Thus, unsuitable temperatures in the mainstem under all alternatives and destabilization of backwaters and nearshore habitats and restricted tributary access under some alternatives would combine to perpetuate conditions unfavorable to warmwater fish. This is of particular concern regarding the special status species: humpback chub, razorback sucker, and flannelmouth sucker.

Flood frequency reduction measures may have mixed effects on native fish. Native fish evolved under massive annual seasonal floods and are well adapted to flooding, but physical changes to the Grand Canyon environment may influence the way these fish respond to floods. Because of reduced sediment, a major flood might result in direct, long-term changes to habitats of native fish, including special status species, but the direct effects on these species are unknown.

Flood releases from the dam are sediment-poor, and the flood frequency and sediment loss from various river reaches may be detrimental. Uncontrolled floods accelerate the loss of fine sediment from the river channel, leading to armoring. Backwaters and other low-velocity habitats used by larval, young-of-year, and juvenile fish depend on nearshore materials such as sand for their existence. Long-term sediment

Table IV-9.—Change in river stage and wetted perimeter associated with reliable minimum flows under each alternative at three sites below Glen Canyon Dam

Alternative/reliable minimum flow	Near Glen Canyon Dam River stage (feet)	Near Glen Canyon Dam Wetted perimeter (feet)	A shallow, narrow riffle in Glen Canyon River stage (feet)	A shallow, narrow riffle in Glen Canyon Wetted perimeter (feet)	Near Lees Ferry River stage (feet)	Near Lees Ferry Wetted perimeter (feet)
No action/maximum powerplant capacity						
1,000 cfs (winter)	3128.9	580.3	3123.9	141.4	3110.9	380.4
3,000 cfs (summer)	3130.9	588.5	3126.6	240.4	3112.4	389.1
High fluctuating flow						
3,000 cfs	+2.0	+8.2	+2.7	+99	+1.5	+8.7
Moderate fluctuating flow						
5,000 cfs	+3.5	+14.	+4.2	+153.4	+2.4	+14.1
Modified low fluctuating flow						
5,000 cfs	+3.5	+14.1	+4.2	+153.4	+2.4	+14.1
8,000 cfs	+5.3	+20.5	+5.9	+193.5	+3.4	+20.2
Interim low fluctuating flow						
5,000 cfs	+3.5	+14.1	+4.2	+153.4	+2.4	+14.1
8,000 cfs	+5.3	+20.5	+5.9	+193.5	+3.4	+20.2
Existing monthly volume steady flow						
9,000 cfs	+5.8	+22.2	+6.5	+203.6	+3.7	+21.8
Seasonally adjusted steady flow						
8,000 cfs	+5.3	+20.5	+5.9	+193.5	+3.4	+20.2
Year-round steady flow						
11,400 cfs	+6.9	+25.9	+7.6	+287.2	+4.3	+25.4

loss would result in an irreversible, irretrievable loss of backwater rearing habitats, further confining recruitment of native fish to the tributaries. Floodflows also may inundate backwaters, which—depending on the timing of floods—could render them less useful to young native fish in the short term.

At the same time, native fish of the Southwest are well adapted to flood events. Native fish have evolved with natural floods in the Colorado River (Minckley and Meffe, 1987); indeed, these floods define river channel fish habitat. Floods may displace non-native competitors and predators, potentially enhancing native fish populations (Minckley, 1991). However, the effects of non-native displacement are short term and reversible. Because of the large pool of potential immigrants to Glen and Grand Canyons from Lakes Mead and Powell, none of the alternatives would eliminate the possibility of non-native warmwater fish reestablishing themselves if suitable habitat conditions exist.

High flows also create and maintain return-current channel backwaters (figure III-16). Without some high flow disturbances, return-current channel backwaters eventually would fill with sediment and vegetation. Some clearing of these backwaters would take place under the alternatives that include habitat maintenance flows (short-duration, high flows within powerplant capacity). However, only the higher-volume beach/habitat-building flows—acting as planned floods—have the potential to restructure these backwater habitats. The magnitude, frequency, and duration of flows necessary to sustain these habitats is still unknown. Several factors must be considered in scheduling habitat maintenance and beach/habitat-building flows:

- Balance between the need to maintain the geomorphology of backwaters and their aquatic productivity
- Presence of strong year classes of native fish
- Rearing periods for native fish

Reattachment bar heights (see the SEDIMENT section of this chapter) provide some insight into maintenance of backwaters under normal operations. In the absence of high flow events, the number and area of backwaters would likely decrease due to filling and vegetation growth.

Endangered fish research flows (likely a seasonally steady release pattern) would be implemented and evaluated through adaptive management. The extent to which steady flows would be permanently incorporated into the selected alternative would depend on evaluation of the research results and a determination by the U.S. Fish and Wildlife Service (FWS). Because these research flows might not occur every year and because results will need to be evaluated, effects could not be integrated into the summary table of impacts. Endangered fish research flows (when they occur) would have impacts on aquatic resources similar to those described for the Seasonally Adjusted Steady Flow Alternative.

Non-Native Warmwater and Coolwater Fish

The same environmental variables that affect native fish also affect non-native warmwater and coolwater fish. For example, no alternative under consideration would increase mainstem water temperatures. Warming of backwaters and nearshore habitats would increase as fluctuations are reduced, and some reproduction may occur in these warmer microhabitats under low fluctuations and steady flow conditions. However, warmwater non-native fish would continue to rely on tributaries for reproduction under all alternatives.

Mainstem recruitment and growth also would be affected by water temperatures. Warmer microhabitats such as backwaters and nearshore sites would continue to be important in providing requirements for young non-native warmwater and coolwater fish.

In general, any change in daily dam operations or other management actions that result in improved habitat conditions for native fish also would improve conditions for non-native warmwater and coolwater fish (table IV-9). For example, habitat maintenance flows designed to prepare backwaters for subsequent use by native fish would also benefit non-native fish. While beach/habitat-building flows may temporarily displace them, non-native warmwater and coolwater fish would quickly reestablish as suitable habitat conditions become available.

Interactions Between Native and Non-Native Fish

Conditions in the mainstem river present obstacles for various life stages of both native and non-native fish. Mainstem water temperatures prevent reproduction, and fluctuating flows destabilize nearshore and backwater habitats important to young fish spawned in tributaries. No alternative directly addresses increasing mainstem water temperatures, but nearshore and backwater microhabitats have the potential to warm into a temperature range more favorable to native and non-native warmwater and coolwater fish. Alternatives that would increase water temperatures or result in more stable conditions in microhabitats would improve habitat conditions for both native and non-native fish.

Nearshore and backwater habitats become more stable, and the potential for increased warming of these microhabitats improves as flow fluctuations reduce in magnitude. Increased warming and stability of microhabitats would improve habitat conditions important for mainstem recruitment and growth for both native and non-native fish.

Conditions for mainstem recruitment and growth would improve over no action conditions under the Modified Low and Interim Low Fluctuating Flow Alternatives, and all three steady flow alternatives. If recruitment and growth increase in response to improving conditions, interactions between native and non-native fish may increase. The potential for increased interaction is greatest under the steady flow alternatives (table IV-8).

Resource scientists are not in agreement about what improving habitat conditions means in terms of interactions between native and non-native fish. One group believes that improving conditions would benefit both native and non-native fish. Another group is concerned that improving habitat conditions for both native and non-native fish may provide a competitive advantage to non-native fish that would ultimately result in adverse effects on native species. This uncertainty is reflected in table IV-8 under the steady flow alternatives and is an important issue for future monitoring and research studies.

Trout

While cold releases limit the ability of warmwater fish to reproduce and grow in the main channel, existing water temperatures are adequate for coldwater fish, including rainbow and brown trout. Because the release temperature is the same among alternatives, no temperature limitation for trout spawning is assumed under any alternative. Lack of seasonal warming may limit trout growth rates and probably limits the diversity of aquatic invertebrates available as trout forage.

Fluctuating flow alternatives would result in more adult stranding mortality than the steady flow alternatives. Higher fluctuations would result in more stranding than would lower fluctuations.

Trout reproduction would be stocking dependent under the unrestricted fluctuating flow alternatives, and possibly self-sustaining under the steady flow alternatives. Under fluctuating flow alternatives, from 60 to 90 percent of redd sites would be affected by periodic dewatering. Under steady flow alternatives, redd sites would be unaffected. Direct effects of daily fluctuations on trout reproduction and survival are concentrated in the first 16 miles of river below Glen Canyon Dam. Impacts downstream of this reach are indirect and center on tributary access and food availability. Access to spawning tributaries would not be limited under alternatives with minimum releases of 5,000 cfs or more (Arizona Game and Fish Department, unpublished data). Periodic low flows (less than 5,000 cfs) under unrestricted fluctuating flows may restrict access, though access may be gained during higher flow periods occurring in the same day.

Unrestricted Fluctuating Flows

No Action Alternative

Aquatic Food Base. Under the No Action Alternative, prolonged exposure (greater than 12 hours) of shoreline would limit the potential of that shoreline zone to support *Cladophora* (Angradi et al., 1992; Blinn and Cole, 1991). Angradi found that 6 to 8 hours of exposure caused significant decreases in *Cladophora* biomass (Arizona Game and Fish Department, 1993). Therefore, extended low flow periods (weekends) would determine the area occupied by *Cladophora* and, in turn, the rest of the aquatic food base that directly or indirectly benefits from it—especially in shallow cobble bars.

Reliable minimum flows under no action would be 1,000 cfs during winter months (Labor Day through Easter) and 3,000 cfs during the remainder of the year. Winter minimums, especially those on weekends, would determine the reliable river stage that would support *Cladophora*. Higher summer minimums would support limited recovery of *Cladophora* in the zone up to the river stage corresponding to 3,000 cfs, but lower winter minimums would again expose it following the Labor Day weekend. River stage and wetted perimeter associated with reliable minimum flows under the No Action Alternative at three sites below Glen Canyon Dam are shown in table IV-9.

The minimum flow between successive daily waves released from the dam increases with distance traveled (see chapter III, WATER). As a result, minimum stage is progressively higher—and the associated wetted perimeter larger—at sites downstream from the dam than it would be if the local minimum flow were the same as that at the dam.

Native Fish. The absence of successful mainstem reproduction, impeded access to spawning tributaries, disrupted mainstem nursery areas, disrupted gonadal maturation (temperature-related), and limited growth potential (temperature-related) would result in a stable to gradually declining abundance of native fish.

Tributary Reproduction.–Owing to low water temperatures, successful reproduction in the mainstem would not occur under no action flows (Valdez, 1991; Maddux et al., 1987). Access to tributaries for reproduction is therefore an important consideration in assessing habitat suitability for native fish.

Under no action, cold mainstem temperatures would restrict humpback chub spawning habitat to the LCR. Maintenance of LCR habitat and protection from catastrophic or adverse chronic events is not assured, so improving mainstem rearing habitat and identifying mainstem or additional tributary spawning opportunities are emphasized.

According to Valdez (1991), daily fluctuations under no action may impede tributary access. Low flows of 1,000 cfs (Labor Day until Easter) and potentially 3,000 cfs (Easter until Labor Day) may limit access to tributaries during some part of each day (except perhaps the LCR, which provides access through its own perennial flows), especially if low river stage at tributary mouths occurred at night when adult spawners would likely be moving. Access is considered unlimited at flows of 5,000 cfs and higher (Arizona Game and Fish Department, unpublished data).

Eggs and larval fish can be flushed from tributaries into the cold mainstem by periodic tributary flood events. Temperature shock to eggs and larval fish acclimated to warmer water may be fatal (Maddux et al., 1987), thus reducing the potential success of tributary spawning. Loss or reduction of a single year-class may not be irretrievable; however, successive losses of year-classes may be irreversible. Short-lived fish, such as speckled dace, are most susceptible. The longer-lived native species also are affected if the condition persists uninterrupted.

Mainstem Recruitment and Growth.–The variable nature of native fish spawning and recruitment makes conclusions about their future difficult to assess. Humpback chub may live to 20 plus years (Minckley, 1991). The upstream range of the humpback chub has contracted and may continue to contract due to death of old individuals in place before the dam, reduced recruitment resulting from unfavorable mainstem habitat conditions, or from unknown factors. The last date the species was reported above Lees Ferry (RM 0) was 1967; at Tiger Wash (RM 25), 1977-78; and at RM 30, 1993 (Angradi et al., 1992; Valdez and Hugentobler, 1993). Reduced range may be directly related to loss of mainstem spawning and nursery areas resulting from fluctuating cold releases.

The long life span of humpback chub provides the species with opportunities to capitalize on favorable conditions for spawning and rearing that may be encountered only rarely. Humpback chub do not appear to move great distances within Grand Canyon, although records show that one individual moved 60 miles. The LCR currently provides habitat for all life stages of humpback chub, including the spawning habitat that apparently supports the current population. Habitat for early life stages in the mainstem is limited. Whether the LCR provides sufficient habitat to maintain viable aggregations of chub in the mainstem is unknown.

Backwaters and shallow nearshore areas along the mainstem are important nurseries for young native fish exiting tributaries. Native fish require the shallow, productive, warm refuges provided by these slackwater areas during their first 2 years of life. Generally, warming of backwaters and nearshore areas occurs during warm months, but warming would be limited by fluctuating flows under no action. Daily fluctuations would continue to destabilize these areas (Valdez, 1991) by both periodically drying and flooding them with cold water.

Juvenile humpback chub, as well as other native species, might be displaced from eddies, near-shore areas, or large backwaters to seek more suitable habitat during fluctuations (Valdez, Masslich, and Leibfried, 1992). Forcing these fish into the main channel may result in direct mortality from several causes including temperature shock and exposure to non-native predators (Arizona Game and Fish Department, 1993). Also, additional energy expenditure would occur. Adults also might be forced to move due to changes in flow, but the energy cost has not been established. Suitable habitat for adults should be available under all flows.

Return-current channel backwaters must be re-created periodically by high flow events. Otherwise, they would eventually fill and be eliminated as a habitat type. Beach/habitat-building flows are not included in the No Action Alternative; therefore, return-current channel backwaters would not be restructured under this alternative except during unanticipated floods.

Riverine conditions that support recruitment of razorback suckers have not been found throughout the species' range, and the Colorado River in Grand Canyon is no exception. It is assumed that conditions that affect other young native fish would affect razorback suckers even though their habitat requirement differs in some respects. Daily fluctuating flows would continue to erode sediment; flush backwaters; and dry out algae, zooplankton, and benthos that are unable to move.

Non-Native Warmwater and Coolwater Fish. The constraints on reproduction, recruitment, and growth of warmwater non-native fish in the main channel are very similar to those limiting native fish. The single most important difference is the large pool of potential immigrants to Glen and Grand Canyons from Lakes Mead and Powell. The No Action Alternative would not eliminate the possibility of non-native fish reestablishing if suitable habitat conditions exist.

Tributary Reproduction.–The effects of the No Action Alternative on warmwater non-native fish would be very similar to those on warmwater native fish. Cold releases, and possibly daily fluctuations and flood events, have considerably reduced the numbers of individuals and numbers of species (Minckley, 1991). Main channel habitat conditions for all warmwater non-natives are marginal. Channel catfish, common carp, and fathead minnow persist, but rely on tributary spawning (and backwater spawning in the case of fathead minnow) to maintain their populations.

Warmwater non-native fish species, such as carp, channel catfish, and fathead minnow present in Grand Canyon before the dam, may be adversely affected by cold temperatures and fluctuating releases (Carothers and Brown, 1991). For related reasons, some non-native fish species (green sunfish and black bullhead) abundant in other Colorado River reaches are found in very low numbers in Grand Canyon, greatly reducing the potential impact of those species on humpback chub (Valdez, 1991).

Conditions continue to favor persistence of rainbow trout and brown trout in upper reaches and common carp and channel catfish in lower reaches of the river. As a result, rainbow trout are the most common non-native fish in Glen Canyon and upper Grand Canyon, while common carp and channel catfish are the most common non-natives in lower Grand Canyon.

Striped bass ascend into Grand Canyon from Lake Mead but do not appear to be establishing themselves. Their presence is seasonal and limited in duration (Valdez, Masslich, and Leibfried, 1992).

Mainstem Recruitment and Growth.– Spawning and rearing habitat for warmwater non-natives is limited in the main channel due to perennially cold releases. Factors that limit the native fish likewise constrain the warmwater non-natives, and their growth is similarly limited

Interactions Between Native and Non-Native Fish. Under no action conditions, the interactions between native and non-native fish described in chapter III, FISH, would continue into the future.

Trout. Growth and condition of trout is related to *Cladophora* in Glen Canyon (Angradi et al., 1992). Extended low flow periods (weekends) would determine the aquatic food base available to trout and, in turn, the growth potential of the fish that directly or indirectly benefit from it. Effects on growth and growth potential would be indirect and potentially reversible.

Under no action, the trout population would be limited to low natural reproduction in the Glen Canyon reach where it is dependent upon main channel spawning. Stranding of adult fish is expected at all 11 of the evaluated stranding sites under minimum flows. Downstream trout reproduction may be limited by access to tributaries, but peak flows likely would provide adequate access, particularly in high water volume winter months.

Adult Stranding Mortality.–Because stranded adults typically are spawning fish, the effects are twofold:

1. Relatively large individuals, the result of several years of accumulated growth in the river and of value to anglers, are removed from the population.

2. Potential reproductive contribution to the population is lost.

Under the No Action Alternative, all 11 stranding pools would continue to isolate fish and result in mortality. These effects would be direct and irretrievable. Davis (1991) suggested that careful strain selection for stocking could reduce the incidence of adult stranding. A recently domesticated strain of trout may spawn in late spring and early summer, taking advantage of higher water volume months.

Glen Canyon Reproduction and Recruitment.–Angradi et al. (1992) reported that more than 90 percent of the redd sites they mapped in the Glen Canyon reach were affected by minimum flows as low as 3,000 cfs. These data suggest that at least 90 percent of the utilized spawning habitat would be within the zone of potential daily fluctuation under no action and, if used by trout, the spawn would likely fail. Actual minimums during peak trout spawning seasons could be as low as 1,000 cfs. Natural reproduction would be directly affected and minimized under this alternative, and population size would be maintained through stocking and regulation.

Downstream Reproduction and Recruitment.–Trout access to tributaries is a result of both river and tributary flow. High peak flows in the river during winter months would provide access to tributaries that have sufficient flow for trout use. As with native fish, low minimums may limit trout access to tributaries. The population of rainbow and brown trout in downstream reaches reflects natural reproduction in tributaries.

Maximum Powerplant Capacity Alternative

Impacts of this alternative would differ from no action only because this alternative could increase the duration of low flows, which could intensify concerns about access to tributaries.

Under this alternative, the potential range in river fluctuations is 1,000 to 33,200 cfs, an increase over no action conditions. Minimum 1,000-cfs flows would be the same as under no action; thus, tributary access for humpback chub, razorback sucker, flannelmouth sucker, and other native and non-native fish would continue to be restricted during certain periods.

The Maximum Powerplant Capacity Alternative could, in some ways, affect **non-native warm-water and coolwater fish** more than **native fish**. Native fish are adapted to systems prone to severe flood events. It has been hypothesized (Minckley, 1991; Valdez, 1991) that wider fluctuations or flood events could temporarily destabilize and displace non-native fish in canyon-bound Southwestern streams. The effects of fluctuation would be direct but, because of the large pool of potential immigrants to Glen and Grand Canyons from Lakes Mead and Powell, the effect would be short term and reversible.

Interactions between native and non-native fish and impacts on **trout** would be the same as under no action.

Restricted Fluctuating Flows

Some effects on fish under the restricted fluctuating flow alternatives share similarities and are discussed in this section. Effects that differ from this general response are described separately under the individual discussions that follow.

Successful spawning of native fish in the mainstem apparently would be prevented by the unchanged temperature of releases from Glen Canyon Dam. Larval and young-of-year nurseries (backwater areas and tributary mouths) would be affected by these alternatives in much the same ways as under no action, particularly during the high volume months of July, August, and September when young fish require warm, sheltered areas.

Daily fluctuations and ramp rates under these alternatives could force movements of both adult and juvenile native fish from preferred sites, directly causing individuals to expend energy and potentially limiting their growth, survival, and reproduction, as under no action (Valdez, 1991; Valdez and Hugentobler, 1993). Frequent fluctuations would limit solar warming of backwaters, would flush out organisms and nutrients important as food resources, and could force the early life stages of native fish—such as humpback chub—out of quiet, protected waters into unfavorable mainstem conditions. The High Fluctuating Flow Alternative would also affect special status fish species directly by restricting access to tributaries during low flow periods.

While the aquatic food base might increase somewhat due to higher minimum flows, that effect could be offset. Reduced fluctuations may reduce the amount of algae and invertebrates in drift. Leibfried and Blinn (1987) explained that rising discharges could increase drift; Arizona Game and Fish Department (1993) reported a positive correlation between coarse particulate organic matter and flow under fluctuating conditions. Valdez and Hugentobler (1993) observed increases in invertebrate drift during declining daily fluctuating discharges. The suggestion is that daily changes in flow may increase the density of invertebrates in drift and, in turn, availability of the aquatic food base to drift-feeding fish. "It is unknown at this time if the drifting food resources are a limiting factor for Colorado River fishes" (Valdez and Hugentobler, 1993).

Turbidity may be increased by fluctuations, with several implications for native fish. Valdez and Hugentobler (1993) observed that turbidity is a primary influence on activity patterns of humpback chub in Grand Canyon. They observed increased presence and activity of adult humpback chub near the surface during daytime hours under turbid conditions, and it has been inferred that near-surface presence may reflect foraging opportunities. Turbidity also may provide cover and a degree of protection from predation. Yard et al. (1993) indicated that the major factors influencing light attenuation were associated with suspended sediment and identified those factors as:

- Sediment discharge from tributaries
- Releases from Glen Canyon Dam
- Sediment differences below major tributaries
- Channel geometry

Turbidity in nearshore areas resulting from flow fluctuation could provide foraging opportunities for adult chub or some protection from predation for young chub.

It has been argued that daily fluctuation may destabilize nearshore habitats and backwaters for young non-native warmwater fish in the same ways as those described for native fish. Daily fluctuation and temperature limitations would continue to suppress reproduction and recruitment of non-native warmwater fishes in the mainstem.

Beach/habitat-building flows are included in these alternatives, and habitat maintenance flows would occur under the Moderate and Modified Low Fluctuating Flow Alternatives. These flows could reverse the long-term trend toward filling of return-current channel backwaters. It is assumed that these scheduled flows would maintain backwaters as a habitat type.

High Fluctuating Flow Alternative

Reliable minimum flows under the High Fluctuating Flow Alternative are 3,000 cfs throughout the year. Minimum flows increase to 5,000 cfs or 8,000 cfs in higher volume months with appropriate power market conditions, but ultimately would return to the minimum reliable 3,000 cfs after a 2- to 3-month increase.

Three-day (holiday) weekends during low volume, unfavorable power market months would determine the reliable river stage that would support *Cladophora*, indicator for the **aquatic food base** as a whole. Increases in river stage and wetted perimeter associated with the increased reliable minimum flow of the High Fluctuating Flow Alternative at three sites below Glen Canyon Dam are listed in table IV-9. Wave transformation effects would increase minimum discharges (thus minimum stage and wetted perimeter) in downstream reaches.

The effects of high fluctuating flows on **native fish** would be very similar to those of no action, with the exception of increasing the aquatic food base. Flood control offered under this alternative would provide limited assurance that riverbed sand would be available for backwater maintenance.

Operations would continue to constrain growth rates and reduce survival of humpback chub, as well as other native species, due to lack of warm nursery areas and continued cold mainstem temperatures. Access to tributaries is uncertain, and during low flows of less than 5,000 cfs, access may be obstructed. Daily fluctuations during high flow months of July and August are estimated to average from 7 to 8 feet in the river reaches important to humpback chub (RM 36 to RM 77). This fluctuation would be particularly adverse to larval, young-of-year, and juvenile life stages and would possibly restrict tributary access by adults. Maintenance of sediment for the above river reach is more negative than under other restricted fluctuating flow alternatives. This would reduce the opportunities to develop backwater habitats. Populations of native fish would be expected to range from stable to gradually declining.

Effects on **non-native warmwater and coolwater fish** would be very similar to those described for no action. **Interactions between native and non-native fish** would be the same as under no action conditions.

Higher minimum flows under this alternative could reduce the effects of **trout** redd exposure over short periods. At each successive minimum flow described by the alternative, a smaller proportion of the redd sites evaluated by Angradi et al. (1992) would be exposed daily, as shown below.

Minimum flow (cfs)	Redds exposed daily (percent)
3,000	90
5,000	83
8,000	59

The trout hatching period can range from 3 to 7 weeks and could probably be accommodated within high volume winter months. However, successful hatching and rearing from larval stages to a size capable of negotiating the fluctuating flows would be less likely. Larval trout and fry would still be forced to move among rearing habitats as river stage fluctuated every day, reducing the likelihood of survival (Persons et al., 1985). Limitations on survival of larval trout and fry would be direct effects of fluctuations. The effects potentially could be offset through stocking and regulation.

As under no action, trout likely would have adequate access to tributaries for spawning. Access probably would be possible at higher flows; it is unknown if the increased minimum flows would enhance access.

The aquatic food base for trout is projected to increase with the increased reliable minimum flow, as would the growth potential for trout.

The High Fluctuating Flow Alternative would result in a slight reduction in stranding, imperceptible change in recruitment from mainstem spawning, no change in access to spawning tributaries for downstream populations, and a minor increase in growth potential for trout.

Moderate Fluctuating Flow Alternative

The **aquatic food base** would increase over no action and high fluctuating flows under the Moderate Fluctuating Flow Alternative. Reliable minimum flows under this alternative would be 5,000 cfs throughout the year. Because the daily range of fluctuations would be set for the entire month based on the monthly volume, minimum flows in higher volume months would be higher than the described minimum of 5,000 cfs. (Projected minimum flows for December, January, and July are above 7,000 cfs.) Ultimately, low flows would return to the minimum reliable 5,000 cfs after a 2- to 3-month increase.

Increases in river stage and wetted perimeter associated with the increased reliable minimum flow of the Moderate Fluctuating Flow Alternative at three sites below Glen Canyon Dam are shown in table IV-9.

Wave transformation effects would increase minimum discharges (thus minimum stage and wetted perimeter) in downstream reaches.

The effects of moderate fluctuating flow on **native fish** would be very similar to those of no action, with the exception of increases to the aquatic food base. Minimum releases of 5,000 cfs would not limit fish access to tributaries. Monthly volumes during the high flow months of July and August during an 8.23-maf water year would result in a mean flow of 16,700 cfs, with daily fluctuations not to exceed 12,000 cfs. For reaches near the LCR, the average daily range would be 5 feet. Very few backwaters would be available due to the high mean flow. The cold water of the main channel would continue to strongly influence the remaining backwaters. Stability of nearshore habitats would be increased due to the reduced range of daily flow and ramp rates, although maximum fluctuations would occur when larval and young-of-year fish leave the tributaries and enter the mainstem. Tributary confluences would benefit from the high mean flow but would be subject to daily fluctuations. Populations are expected to range from stable to gradually declining.

Without some type of disturbance—such as periodic high flows—return-current channels that support backwaters would eventually fill with sediment, become colonized with vegetation, and lose their habitat value for native fish. Periodic high flows are assumed to re-form return-current channels and thus maintain conditions favorable for native fish at these sites.

The Moderate Fluctuating Flow Alternative includes habitat maintenance flows designed to re-form beaches and backwaters. Habitat maintenance flows would provide high (30,000 cfs), steady flows for up to 2 weeks each spring when Lake Powell is not predicted to fill. The scheduling of flows in March is not intended to mimic the pattern of high spring flows that historically occurred later in the season. Instead, maintenance flows in March would prepare backwaters for use by larval and young-of-year native fish when they move into the mainstem from tributaries later in the year. Under this alternative, daily fluctuations would inundate backwaters and associated sandbars, thus reducing the assumed benefits derived from providing habitat for early life stages of native fish. As discussed previously, some caution must be exercised when scheduling habitat maintenance flows since the frequency and duration needed to maintain backwaters is unknown.

Without some type of disturbance, backwater habitat would become progressively more stable and thus more suitable for **non-native warmwater and coolwater fish**. Fathead minnow and common carp, in particular, could dominate in very stable backwaters (Maddux et al., 1987). Lower fluctuations and protection from floodflows under this alternative would be beneficial to non-native fish over no action conditions. However, habitat maintenance flows would offset these assumed benefits and cause some displacement of individual non-native fish.

Interactions between native and non-native fish under this alternative would be the same as those that occur under no action conditions.

Under the Moderate Fluctuating Flow Alternative, the daily range of fluctuation would be decreased, and the minimum flow would be increased. Both of these factors could prove beneficial to **trout**. Higher reliable minimum flows would reduce the degree of stranding from that experienced under no action. Monthly minimums of 5,000 cfs would have isolated only 80 percent of the trout stranding pools evaluated by Angradi et al. (1992). Additionally, because the daily range would be limited by the mean daily release from Glen Canyon Dam, the absolute minimum would increase during high volume months. (Projected minimum flows for December, January, and July are above 7,000 cfs.) As a result, potentially fewer trout stranding pools would become isolated, especially during high volume months.

Higher minimum flows under this alternative would reduce the effects of trout redd exposure over short periods. A minimum flow of 5,000 cfs would have exposed approximately 83 percent of the trout redd sites evaluated by Angradi et al. (1992). Because the daily range would be constrained under this alternative, the actual minimum flow might be greater than the required minimum. The daily range may also limit the realized maximum flow and force trout to select redd sites lower on gravel bars. These sites might be proportionately less susceptible to exposure. Days with flows below 3,000 cfs would be eliminated, and the daily range of fluctuation would be constrained to less than 12,000 cfs per day.

Trout would have adequate access to tributaries for spawning. Access would be possible at higher flows, and it is unknown if the increased minimum flows would enhance their access. The aquatic food base for trout would increase with the increased reliable minimum flow, as would trout growth potential.

Overall effects of the Moderate Fluctuating Flow Alternative on trout would include a reduction in stranding effects, a potential increase in recruitment from mainstem spawning, unconstrained access to spawning tributaries for downstream populations, and moderate increase in growth potential.

Modified Low Fluctuating Flow Alternative

Dam release patterns under the Modified Low Fluctuating Flow Alternative would be similar to those under the Interim Low Fluctuating Flow Alternative except for the inclusion of habitat maintenance flows and an increased ramp rate of 4,000 cfs per hour. The habitat maintenance flows would re-form backwaters and help maintain these important sites for young fish.

Under this alternative, reliable minimum flows would be 5,000 cfs throughout the year, with flows no less than 8,000 cfs from 7 a.m. to 7 p.m. As a result, the shoreline zone between the reliable river stages associated with 5,000- and 8,000-cfs releases would support an **aquatic food base**. The quality of this portion of the aquatic food base would not be expected to be comparable to the zone below 5,000 cfs because of its periodic, daily exposure. Areas just above the 5,000-cfs stage would be better maintained than areas just below the 8,000-cfs stage because the latter would be exposed for greater periods.

In high volume months, minimum flows would be greater than the reliable minimums. Weekend flows would still be relatively low, however, so little development of the aquatic food base would take place above the 8,000-cfs river stage. Increases in river stage and wetted perimeter associated with the increased reliable minimum flow of this alternative at three sites below Glen Canyon Dam are shown in table IV-9. As with other fluctuating flow release patterns, wave transformation effects would increase minimum discharges (thus minimum stage and wetted perimeter) in downstream reaches.

Drift of food items from upper reaches would be likely, as with other fluctuating flow alternatives.

Effects on **native fish** would be similar to those under other fluctuating flow alternatives in that fluctuating flows disrupt backwater and nearshore areas. However, this alternative includes the narrowest range of flow fluctuations and habitat maintenance flows. Therefore, some increases in the aquatic food base and stability of backwater and nearshore nursery areas would be expected over no action. Additionally, the reduced fluctuating flows might allow for limited spawning in the mainstem near warm spring inflows as documented during the 1993 summer season of interim operations (Arizona Game and Fish Department, 1994). There currently is no indication that such spawning would result in recruitment. The increased stability of nursery habitats could be offset by the higher daily low flows released during July and August, which could inundate backwaters and reduce their numbers. Increases in the aquatic food base and decreases in fluctuation would result in the potential for minor population increases.

Under this alternative, the potential range in river fluctuations is 5,000 to 25,000 cfs, a reduction from no action conditions. Tributary access would not be limited with 5,000-cfs minimum releases.

The habitat maintenance flows would be designed to re-form and maintain backwaters in a productive state for native fish. Without such flows, it is assumed that backwaters would fill with sediment, become colonized by vegetation, and progressively lose their habitat value for young native fish.

Without disturbance, nearshore habitats become progressively more stabilized. This increasing stability is assumed to improve habitat conditions for **non-native warmwater and coolwater fish.** Hence, in addition to re-forming and interrupting trends toward backwater stabilization, maintenance flows may also temporarily displace individual non-native fish.

Some stabilization in nearshore habitats under this alternative would result in a potential minor increase in **interactions between native and non-native fish**.

Impacts on **trout** would include reduced stranding, potential increase in recruitment from mainstem spawning, and potential moderate increase in growth potential.

Minimum flows under this alternative would reduce the degree of stranding experienced in the Glen Canyon reach. Monthly minimums of 5,000 cfs would have isolated only 80 percent of the pools evaluated by Angradi et al. (1992). The requirement to increase minimum flows to 8,000 cfs between 7 a.m. and 7 p.m. could also limit the period of isolation for some stranding pools. Stranding pools recaptured by the river during this 12-hour period could not cause the same rate of mortality. Angradi et al. (1992) showed that stranded trout died in 4 to 64 hours after stranding.

Higher minimum flows under this alternative would reduce effects on trout redd and fry habitat similarly to the Moderate Fluctuating Flow Alternative. In addition, the aquatic food base for trout would increase with the increased reliable minimum flow, as would trout growth potential.

Interim Low Fluctuating Flow Alternative

Dam release patterns under this alternative would be similar to those of the Modified Low Fluctuating Flow Alternative except for the exclusion of habitat maintenance flows. These effects, which focus on the **aquatic food base** and **trout**, are discussed under the Modified Low Fluctuating Flow Alternative.

Increases in river stage and wetted perimeter associated with the increased reliable minimum flow of the Interim Low Fluctuating Flow Alternative at three sites below Glen Canyon Dam are shown in table IV-9.

Wave transformation effects would increase minimum discharges (thus minimum stage and wetted perimeter) in downstream reaches.

The effects of low fluctuating flows on **native fish** would be similar to those under no action in that fluctuating flows disrupt backwater and nearshore areas. However, a relative increase in stability of backwater and nearshore nursery areas would occur due to the decreased range of flow fluctuations with a higher minimum reliable flow. There would be a moderate increase in the aquatic food base. Additionally, the reduced fluctuating flows under interim operations allowed for limited spawning in the mainstem near warm spring inflows during 1993 (Arizona Game and

Fish Department, 1994). However, there currently is no indication of recruitment of these mainstem spawned fish. The increased stability of nursery habitats could be offset by the higher minimum flows released during July and August, which could inundate backwaters and reduce their numbers. Increases in the aquatic food base and decreases in fluctuation would result in the potential for minor population increases.

Daily fluctuations in river stage would be expected to average approximately 3 feet in reaches RM 36 to RM 77 during July and August, when flows would range from 12,000 to 20,000 cfs. Young humpback chub and other native fish may experience some increased growth owing to more stable nearshore habitats. Drift of food items from upper reaches would be likely, as under other fluctuating flow alternatives.

Preliminary information from studies conducted during interim operations (flows similar to this alternative) showed that juvenile humpback chub could hold their position in reaches adjacent to the LCR and not be moved downstream (Valdez, Wasowicz, and Leibfried, 1992). Juvenile humpback chub that remain in this area might benefit from the higher food production in the upper mainstem and from the reduced numbers of fish predators compared to the lower reaches. Tributary confluences would be somewhat ponded but still subject to daily fluctuations. Humpback chub may move from some habitats, which would subject the species to some unknown energy cost; however, the cost may not be significant (Valdez, 1991).

Ramp rates of 2,500 cfs up and 1,500 cfs down, with an allowable daily change in flow between 5,000, 6,000 and 8,000 cfs, would improve habitat conditions for humpback chub. Minimum 5,000-cfs flows are 4,000 cfs greater than under no action; thus, tributary access for humpback chub, razorback sucker, and flannelmouth sucker would be unrestricted.

The effects of the Low Fluctuating Flow Alternative on **non-native warmwater and coolwater fish** would differ from those under no action and the other fluctuating flow alternatives in one respect: the advantage of progressively more stable backwaters. As backwater stability increases, they would become progressively more suitable for some non-native fish. Fathead minnow, in particular, could dominate very stable backwaters (Maddux et al., 1987) and might reflect a minor increase in the abundance of non-native warmwater fish. Factors that limit non-native warmwater fish would be very similar to those that constrain native warmwater fish, and their responses could be similar. Daily fluctuations would continue; therefore, the optimal stable conditions for warmwater non-native fish would not occur. Because the daily range of fluctuation would be reduced, this alternative would less likely displace individual non-native fish.

Under the Interim Low Fluctuating Flow Alternative, nearshore habitats would be more stable than under no action, creating the potential for a minor increase in **interactions between native and non-native fish**.

Impacts on **trout** would include reduced stranding, potential increase in recruitment from mainstem spawning, and potential moderate increase in growth potential as discussed under the Modified Low Fluctuating Flow Alternative.

Steady Flows

Many of the impacts of the steady flow alternatives on fish are similar, and these are discussed in this section. Effects that differ from this general response are described separately under the individual alternatives that follow.

Reliable minimum flows under the steady flow alternatives all would equal or exceed 8,000 cfs. As a result, shoreline zones up to at least the reliable river stage associated with 8,000-cfs releases would support an aquatic food base. Shoreline zones inundated seasonally or monthly could be recolonized by *Cladophora*, but that portion of the aquatic food base would not be as stable as in zones below the reliable minimum river stage.

Under steady flows, successive daily release waves would not be generated. As a result, flows released from Glen Canyon Dam would not progressively increase in stage downstream except for contributions from tributary flow.

The absence of water velocity changes typical of fluctuating flows could reduce the amount of *Cladophora* and invertebrate drift, which could reduce the availability of fish forage and slow its transport downstream. Leibfried and Blinn (1987) showed a positive connection between increasing range of discharges and the drift of *Gammarus* during transition from steady flows to fluctuating flows. *Cladophora* and chironomid larvae did not show similar responses. Angradi et al. (1992) showed increases in concentration of coarse particulate organic matter (largely *Cladophora* debris) associated with increasing daily flow. Blinn et al. (1992) observed that steady flow conditions decreased *Cladophora* and invertebrates in the Lees Ferry reach. The significance of reduced drift is unknown.

Successful spawning in the main channel would be limited by cold releases from Glen Canyon Dam under all steady flow alternatives. Stable flows would likely result in limited spawning habitat for native fish species near warmwater springs in the mainstem or near warmwater inflow at tributary confluences. This reasoning is supported by recent evidence indicating that limited humpback chub spawning occurred under the reduced daily fluctuations of interim operations (Arizona Game and Fish Department, 1994). While moderately stable backwaters could warm somewhat, there is no evidence that they provide spawning habitat for native fish, other than speckled dace.

With the allowable daily change in flow not exceeding 2,000 cfs (±1,000 cfs) per 24 hours, inundation and exposure of habitats along the channel margins would be limited. This would allow for increased warming of connected backwaters, which would benefit young-of-year and other subadult humpback chub in the mainstem. Young fish using nearshore habitats might not be forced to expend energy seeking suitable habitats when flow conditions change. Food production (zooplankton and invertebrates) in backwaters might be increased by stable water levels and higher water temperatures. Availability of food as drift from upstream reaches might be decreased due to reduced flows or ramp rates (Leibfried and Blinn, 1987).

Steady flows might adversely affect maintenance of backwaters. Backwaters become isolated and change to terrestrial habitats as they fill with sediment. Releases higher than normal operations might be necessary to maintain backwaters.

Beach/habitat-building flows would be designed and planned to redistribute sediment from pools to channel margins. These flows also would assist in controlling non-native fish species that might increase as conditions became more favorable for warmwater fish in general.

Tributary confluences that serve as rearing habitats for young fish would benefit because they would not be subject to daily stage changes.

Improved habitat conditions for native fish species (including endangered fish) might also benefit non-native fish species that are competitors or predators of endangered fish. The impacts of a possible increase in non-native species on endangered fish are unknown. Native fish species persist over non-natives in the tributaries, and operational changes would not be expected to change this relationship. Monitoring the fish community would be an essential element of any alternative. Continued collection of data on species interactions, habitat requirements, and food resources as they relate to operations and the dynamics of a riverine system would be necessary.

As under the fluctuating flow alternatives and no action, increased backwater stability favors some non-native warmwater fish as well as native fish. Fathead minnow and common carp, in particular, could benefit from stable backwaters (Maddux et al., 1987). Growth of warmwater non-natives and natives would be limited by temperature. Stable backwater areas could enable non-native fish to out-compete native fish for resources that enhance growth. Steady flow alternatives have the greatest potential for enhancing conditions for non-native warmwater fish.

Nearshore and backwater microhabitats would be stabilized under steady flow alternatives. Interactions between native and non-native fish would experience a potentially moderate increase over no action conditions. The outcome from increased interaction between native and non-native fish under steady flow alternatives is uncertain.

Steady monthly flows under these alternatives would reduce trout stranding compared to no action. Additionally, conditions likely to strand fish in the Glen Canyon reach would be limited to monthly or seasonal adjustments. Even then, only downward adjustments would strand fish. As a result, significantly fewer pools would become isolated. Once a pool became isolated, it would be highly unlikely for the river to recapture the pool and release stranded fish. Those stranded during seasonal flow adjustments would likely perish.

Higher steady flows under these alternatives would reduce the effects of redd exposure during at least 30-day periods. Redd exposure is not likely without daily fluctuations. Downward adjustments in flow between months could expose redds.

Because flows would be steady and dependable over 30-day, seasonal, or annual periods, successful emergence of larval fish from redds would be likely. Larval, fry, and subadult trout would not be forced to move among rearing habitats, resulting in higher likelihood of survival. Enhanced redd success and increased recruitment would be direct effects of monthly steady flows. All three of the flow-related factors that Persons et al. (1985) noted as negatively associated with year-class strength for trout would be addressed by these alternatives.

The relatively high reliable minimum flows of these alternatives would maintain access to tributaries and increase trout growth potential.

Existing Monthly Volume Steady Flow Alternative

Reliable minimum flows under this alternative typically would exceed 9,000 cfs, even though the absolute minimum is 8,000 cfs. As a result, shoreline zones up to at least the reliable river stage associated with 9,000-cfs releases would support an **aquatic food base**. Shoreline zones inundated monthly by higher steady flows could be recolonized by *Cladophora*, but that portion of the aquatic food base would not be as stable as in zones below the reliable minimum river stage.

Increases in river stage and wetted perimeter associated with the increased reliable minimum flow under the Existing Monthly Volume Steady Flow Alternative at three sites below Glen Canyon Dam are listed in table IV-9.

Many of the impacts on **native fish** that occur under no action also would occur under this alternative, though the mechanisms by which the effects occur would differ. For example, daily fluctuations would be replaced by discharge changes between months. While the frequency of discharge changes would be drastically reduced under this alternative, some of the effects could still occur.

Low flows in March through May would be counter to historic hydrologic patterns of high spring flows, which may provide "cues" to stimulate spawning in native fish such as humpback chub (Valdez, 1991). Under this alternative, high flows in the summer (June through August) would not support backwater or nursery areas in the mainstem but would contribute to tributary access. Food resources in backwaters and other nearshore habitats might not have sufficient time (1 month) to develop before flows change.

The daily flushing of backwaters would be eliminated under this alternative, but high steady flows during high volume summer months could inundate return-current channel backwaters when they would be most valuable to native fish as rearing habitats. Adjustments between months could force movement of juvenile fish, requiring energy expenditures and potentially exposing young fish to predation for relatively short periods.

Some nursery backwaters might not be formed (i.e., they would remain eddies) by the higher June, July, and August flows of this alternative. Those that did form would be stable during each month and would warm, providing rearing habitat for juvenile native fish. Rearing habitats would be destabilized only temporarily by the monthly adjustments in steady flows, though the frequency of these events would be much less than under the No Action Alternative. An increased aquatic food base, along with stable backwaters (but perhaps fewer in number) would create potential for stable to increasing numbers of native fish.

Spawning and rearing habitat for **non-native warmwater and coolwater fish** would be limited in the main channel due to perennially cold releases. While the number of available back-waters may be reduced due to high summer flows, the stability of the remaining backwaters could directly increase the recruitment of some non-natives (particularly fathead minnow and carp). The absence of daily fluctuations would eliminate displacement of individual non-native fish. Beach/habitat-building flows could, how-ever, destabilize populations of non-native fish.

Under the Existing Monthly Volume Steady Flow Alternative, **interactions between native and non-native fish** would experience a potentially moderate increase over no action.

Monthly steady flows (all monthly flows would likely be greater than 9,000 cfs) would have isolated only 45 percent of the **trout** pools evaluated by Angradi et al. (1992). Stranding would occur only during downward adjustments between months. Overall, the Existing Monthly Volume Steady Flow Alternative would greatly reduce trout stranding, greatly increase recruitment from mainstem spawning, maintain access to spawning tributaries for downstream populations, and possibly increase growth potential.

Seasonally Adjusted Steady Flow Alternative

Reliable minimum flows under this alternative typically would equal or exceed 8,000 cfs. As a result, shoreline zones up to at least the 8,000-cfs stage would support an **aquatic food base.** Shoreline zones inundated seasonally by higher steady flows could be recolonized by *Cladophora,* but that portion of the aquatic food base would not be as stable as in zones below the reliable minimum river stage.

Increases in river stage and wetted perimeter associated with the increased reliable minimum flow under the Seasonally Adjusted Steady Flow Alternative at three sites below Glen Canyon Dam are listed in table IV-9.

The effects of this alternative on **native fish** would differ markedly from those of no action in many ways. While the alternative would establish some conditions that would enhance native fish, those same conditions could also enhance conditions for non-native warmwater fish that compete with or prey on the natives. The two effects could offset one another. There is concern among resource specialists about potential increased interaction (competition and predation) if mainstem temperatures increase significantly. The swift water habitats of Marble and Grand Canyons may favor the native species.

This alternative provides for an annual spring peak of 18,000 cfs to facilitate humpback chub spawning. Access to tributaries would be enhanced in the spring. Releases of 9,000 cfs in August and September would support backwater habitat development. Habitats for early life stages of humpback chub would stabilize and warm somewhat during the steady, lower flow period (July through September), resulting in increased growth and survival of young-of-year humpback chub. Less movement and, consequently, reduced energy expenditure would be anticipated for the juvenile humpback chub during steady flows. Shallow, protected juvenile habitats associated with tributary inflows, cobble shorelines, and cobble riffles would likely be enhanced (Valdez, 1991).

Food resources such as algae, zooplankton, and invertebrates might develop in seasonally inundated zones. The response to this quarterly change is unknown but might be more beneficial than monthly changes in river stage.

Under this alternative, a sediment balance that allows backwater development would be predicted to occur during 86 percent of the years (50-year sediment supply) in the reach important to humpback chub (RM 36 to RM 77). The higher spring flows should help redistribute this sediment and flush out backwater habitats.

A habitat maintenance flow in March would re-form return-current channels and prepare backwaters for later use by fish during the lower flows of summer. These flows are needed to prevent successional changes that favor non-native fish and eventually terrestrial vegetation.

According to Maddux et al. (1987), high steady flows during April, May, and June could increase spawning at tributary mouths and facilitate access to tributaries for spawning.

Access to spawning tributaries, stabilized nursery areas, and improved aquatic food base would allow potential major increases in the abundance of native fish.

The effects of the Seasonally Adjusted Steady Flow Alternative on **non-native warmwater and coolwater fish** would differ considerably from those under no action. One notable area of difference would be the effect of stable backwaters. As backwaters stabilized, they would become progressively more suitable for some non-native fish.

The abundance of warmwater non-natives could be enhanced under this alternative. Increased late summer stability of backwaters could result in higher recruitment rates for some warmwater non-natives, particularly fathead minnow and carp. The absence of daily flow fluctuations would eliminate daily displacement of individual non-native fish from backwaters. Increased water clarity in backwaters may result in increased predation by non-native fish upon native fish. There is disagreement among resource specialists as to whether annual habitat maintenance or beach/habitat-building flows would be of sufficient magnitude to destabilize non-native fish populations.

Nearshore and backwater microhabitats would be stabilized under the Seasonally Adjusted Steady Flow Alternative, resulting in a potential moderate increase in **interactions between native and non-native fish.**

Steady monthly flows under this alternative would reduce the degree of **trout** stranding experienced under no action. Monthly steady flows of 8,000 cfs or greater would have isolated only 45 percent of the pools evaluated by Angradi et al. (1992). Opportunities for stranding would occur during downward adjustments between seasons. On the whole, the Seasonally Adjusted Steady Flow Alternative would greatly reduce stranding effects, increase recruitment from mainstem spawning, maintain access to spawning tributaries for downstream populations, and increase trout growth potential and condition.

Year-Round Steady Flow Alternative

Reliable minimum flows under this alternative typically would equal or exceed 11,400 cfs. As a result, shoreline zones up to at least the reliable river stage associated with 11,400-cfs releases would support an **aquatic food base.**

The aquatic food base could be enhanced, though it might not be as readily swept into the drift and transported downstream in the absence of fluctuations (Angradi et al., 1992). Whether this would limit food production in downstream reaches is uncertain.

Increases in river stage and wetted perimeter associated with the increased reliable minimum flow under the Year-Round Steady Flow Alternative at three sites below Glen Canyon Dam are listed in table IV-9.

According to Valdez (1991), the moderately high constant flows (11,000 to 12,000 cfs) of this alternative under normal operations would be sufficient to provide access to tributaries by **native fish.** Because of the year-round nature of these releases, access should be available throughout the spawning period.

Access to tributaries for spawning fish would be enhanced, and ponding of tributary confluences—which benefits larval fish—would be constant throughout the year. This ponding might benefit humpback chub, but might benefit non-native species as well. The number of backwater habitats would decrease due to the high mean flows, but nearshore and backwater habitats would be stable throughout the year.

A net sediment balance for the reach important to humpback chub would be predicted to occur every year (50-year sediment supply), supplying the most sediment for that reach of any alternative. Beach/habitat-building flows may be necessary to create backwaters or other habitats.

Some larval and young-of-year nurseries (backwater areas and tributary mouths) and juvenile habitats would likely be enhanced under this alternative. However, many return-current channel backwaters would be inundated by the high steady discharges typical of this alternative. Backwater stability during July, August, and September would provide dependable rearing areas that warm daily, resulting in improved growth for young-of-year fish. Too much stability, however, could decrease the acceptability of backwater areas as rearing sites. Long-term stability could result in establishment of marsh vegetation and eventually riparian vegetation, ultimately eliminating these stable backwater areas as native fish rearing areas. High, flushing releases—such as the beach/habitat-building flows discussed earlier—would be necessary to maintain these habitats; however, there is disagreement concerning the desired frequency of such events.

Shallow, protected juvenile habitats associated with tributary inflows, cobble shorelines, and cobble riffles might not be enhanced under this alternative (Valdez, 1991). These sites typically would be limited at moderate to high flows.

Improved access to spawning tributaries, relatively stable nursery areas in the short term, limited habitat for juvenile fish, and potentially enhanced aquatic food base would result in stable to potentially increased numbers of native fish.

The absence of fluctuations and between month adjustments virtually would eliminate destabilization of **non-native warmwater and coolwater fish** by flow-related factors. Very stable flow conditions and reliable access to tributaries for spawning would result in population increases. Backwater habitats could be limited under this alternative because they tend to form at lower flows, but those that formed would provide very stable rearing habitats for warmwater non-natives, which could directly increase recruitment (particularly of fathead minnow and common carp).

A potential moderate increase in **interactions between native and non-native fish** would occur under this alternative.

Year-round steady flows would reduce the degree of **trout** stranding experienced under no action. Monthly steady flows of 11,400 cfs or greater would have isolated none of the pools evaluated by Angradi et al. (1992). Stranding would occur only during adjustments to accommodate forecast change. Therefore, the Year-Round Steady Flow Alternative would result in greatly reduced stranding, greatly increased recruitment from mainstem spawning, access to spawning tributaries for downstream populations, and increased growth potential.

VEGETATION

Issue:

How do dam operations affect VEGETATION throughout Glen and Grand Canyons?

Indicators:

Area of **woody plants** and species composition
Area of **emergent marsh plants**

Glen Canyon Dam operations affect downstream vegetation through several different mechanisms, especially daily release patterns repeated over time and major uncontrolled flood releases. Effects from these mechanisms are reflected as changes in both plant abundance and species composition. Such changes are directly linked to changes in sediment deposits that support riparian vegetation and to water release patterns that provide water for plant growth. Thus, the abundance and composition of the riparian plant community are influenced through effects on sediment and water from daily release patterns and major flood events.

Effects resulting from each alternative are represented by changes in the vegetation indicators identified in chapter III. Because models used for this analysis are still under development, the results presented here are subject to change as more information becomes available and the models are refined.

Analysis Methods

The short-term period of analysis is defined as 5 to 20 years following implementation of an alternative. During this time span, it is assumed that changes in vegetation would closely follow changes to exposed sediment deposits resulting from daily release patterns. Detailed analysis of vegetation generally is limited to the river corridor between the dam and Separation Canyon (although data are available only to Diamond Creek). Below Separation Canyon, riparian vegetation along the river corridor is linked to water levels in Lake Mead.

Although no major flood events are included in short-term analyses, different water years—ranging from low through moderate to high—are anticipated. Infrequent releases above the maximum flow identified for each alternative, habitat maintenance flows, and beach/habitat-building flows of unknown stage may occur in the short term.

It is impossible to predict the types or the sequence of water years that would occur in the future. The basic analysis assumes a sequence of minimum release years with modifications where appropriate. Minimum release years would maximize differences in riparian vegetation responses to flows identified for each alternative. The reader should note that higher water volumes would result in stage conditions similar to alternatives with higher maximum flows. Thus when medium and high water years are interspersed with minimum release years in the future, the differences in plant responses presented in the following analysis will be diminished, and alternatives would become more similar in terms of their effects on riparian vegetation.

The long-term period of analyses is defined as the period from 20 to 50 years following implementation of an alternative. Changes in vegetation during this period become more difficult to predict but are assumed to closely follow changes to exposed sediment deposits. Sediment deposits are expected to reach a state of dynamic equilibrium (see chapter IV, SEDIMENT). Area coverage and species composition of vegetation during this period would stabilize within the constraints of sediment and discharge characteristics of each alternative.

Woody Plants

Analyses of change in area coverage of woody plants rely on previous analyses of active width of unstable sandbars (see chapter IV, SEDIMENT). It is assumed that the average active width of unstable sandbars computed for each of the 11 river reaches under analysis can be subtracted from no action conditions to yield an estimate of sandbar stability for each action alternative. These stabilized sandbar widths are assumed available for plant growth and provide the estimates for change in area of woody plants (figure IV-13). While the width of stabilized sandbars can be computed, such widths may not actually occur at all beaches because some parts of the canyon are too narrow. The data are useful, however, in a comparative sense. The data are presented as a range in feet and percentages from smallest river reach change to largest reach change.

Some alternatives would include an annual habitat maintenance flow designed to move and deposit sediment at higher elevations than would be possible under the alternatives' maximum flows. These flows would affect existing vegetation and those plants that would develop in areas of stabilized sandbars up to an elevation equivalent to the maintenance flow stage.

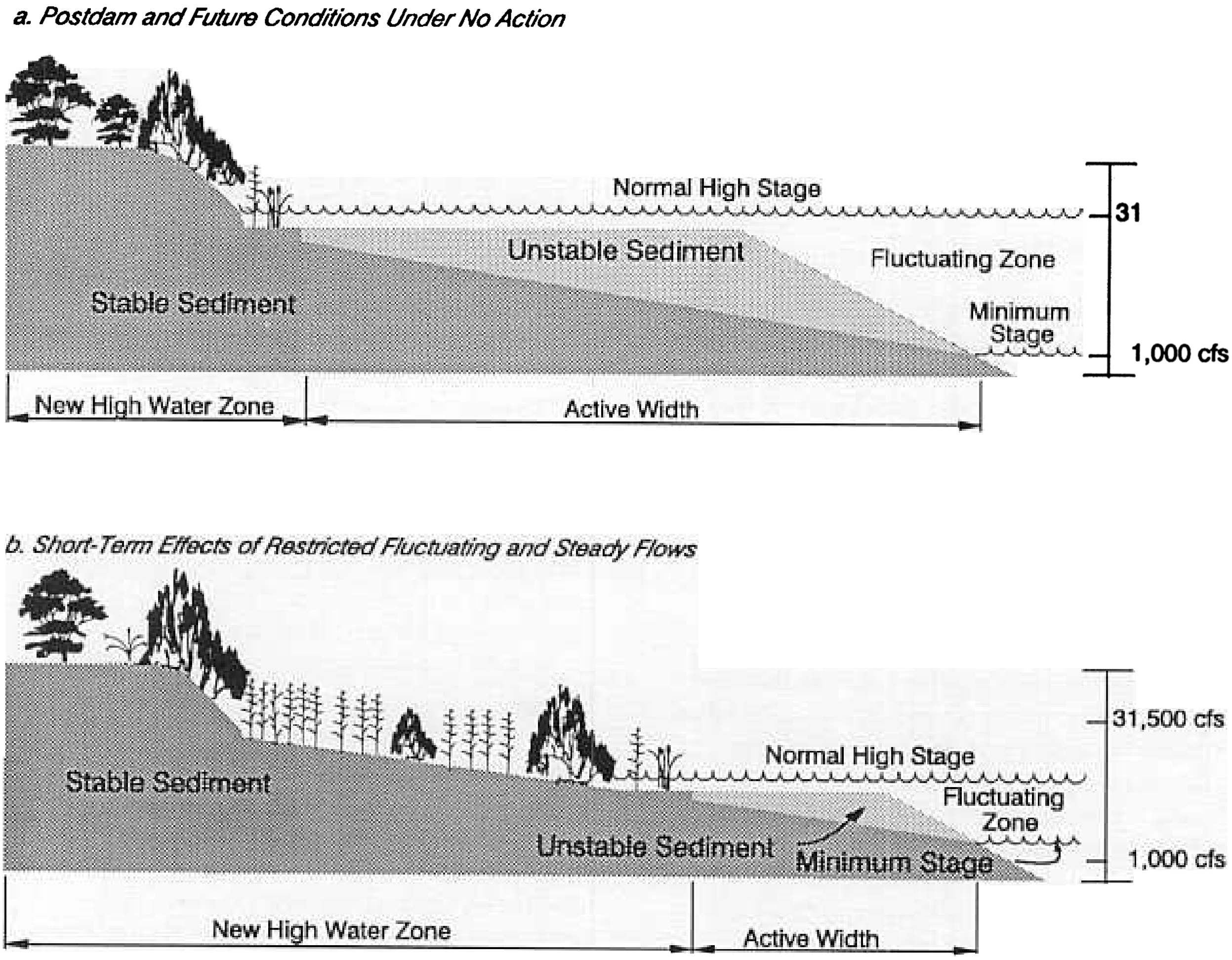


Figure IV-13.—Reduced maximum flows would affect riparian vegetation in the new high water zone (NHWZ) by reducing the width of unstable sandbars and, thus, increasing the area of stable deposits available for plant development. In general, mesquite occupies the upper, dryer elevations with other plants occupying sites closer to the high flow stage (a). Tamarisk, willow, horsetail, and cattails also would develop on suitable sites exposed by reduced high flows (b). Some mortality of woody plants may occur at upper elevations of the NHWZ under alternatives with reduced maximum flows. However, changes in species composition (and area) depend on site-specific characteristics and cannot be estimated.

However, it is assumed that because of limited duration and magnitude, such flows would not scour or drown plants. Some burial of plants would occur. Partial burial may not affect plants, while complete burial may provide an advantage for plants able to grow through the covering sediment. Burial-tolerant woody plants include tamarisk, willow, and arrowweed.

The effects of habitat maintenance flows on riparian plants are speculative at this time and would be monitored closely. However, the following pattern appears reasonable based on plant responses after the 1983-86 high flows. New plant growth below the 30,000-cfs stage may be buried during the first few maintenance flows. Plants that survive burial would grow up through new deposits and contribute to an increase in area of riparian vegetation. In time, some level of stability would develop so that plants would no longer be affected by burial.

An estimate of the maximum effect of maintenance flows, based on active width of unstable sandbars, is presented. However, because of their limited magnitude and short duration, it is assumed that maintenance flows would not affect the area of vegetation to the degree indicated by active width analyses. Thus, for alternatives with maintenance flows, the future area of woody riparian plants is assumed to reach some level between estimates of stabilized sandbar widths before and following such flows.

Beach/habitat-building flows would be an important element of all alternatives except the Maximum Powerplant Capacity and the No Action Alternatives. For vegetation, the magnitude and duration of these flows are important considerations. In order to deliver water to the entire new high water zone (NHWZ), flows would have to be at least 40,500 cfs.

Discharges delivering water to stage elevations equivalent to 40,500 cfs or greater would affect vegetation in at least three ways. First, such flows periodically would provide water to riparian plants in the NHWZ. Second, depending upon stage and duration, beach/habitat-building flows may eliminate some plants, such as mesquite and acacia, that establish in the upper elevations of the NHWZ but cannot tolerate extended inundation. Finally, some burial and scouring of plants would occur with effects that would largely depend on the species and flow magnitude and duration (see chapter III, VEGETATION).

Under the restricted fluctuating and steady flow alternatives, periodic beach/habitat-building flows would disrupt the level of stability that would develop between sediment, plants, and habitat maintenance flows. Sediment deposits would be reworked and some plants lost. A new level of stability would become established following a beach/habitat-building flow and continue until the next high flow.

The NHWZ vegetation that developed in the short term would occupy the same area and have basically the same species composition in the long term (figure IV-14). In the long term, it is assumed that stage reduction would affect woody riparian plants in the upper elevations of the NHWZ through a replacement of tamarisk, willow, and other plants by mesquite and other plants requiring less moisture. Willow, which is less drought-resistant, would disappear first (in the short term) with tamarisk persisting for some time. The abundance of mesquite and other plants would be influenced by beach/habitat-building flows.

All alternatives except the No Action and Maximum Powerplant Capacity Alternatives include flood frequency reduction measures. Effects on the old high water zone (OHWZ) associated with reduced flood frequency are assumed to be identical for all alternatives and are discussed here rather than under each alternative.

Recruitment (addition of young plants to the population) in the OHWZ is assumed to require conditions historically created by periodic high flooding. Without flooding, young riparian plants would not be added to the OHWZ and, thus, would not be available to replace mature plants as they die. More drought-tolerant desert plants may gradually invade the OHWZ. Future major flood events are expected to be so far apart that any differences in flood frequencies between alternatives would not be detected during the long-term period of analyses. Thus, for the purposes of analysis, all alternatives are assumed to contribute equally to the decline of riparian vegetation in the OHWZ.

Because many plant species in the OHWZ are long-lived, changes would be difficult to detect during both the short- and long-term periods of analyses. A more noticeable change would be the continuing establishment of honey mesquite and other species from the OHWZ into the upper (dryer) elevations of the NHWZ. These species would be important components of the riparian zone that develops under any alternative.

It is assumed that at some future time, one or more major uncontrolled floods would occur. In this analysis, a major flood is assumed to occur after 50 years for alternatives with flood frequency reduction measures. For the No Action and Maximum Powerplant Capacity Alternatives, at

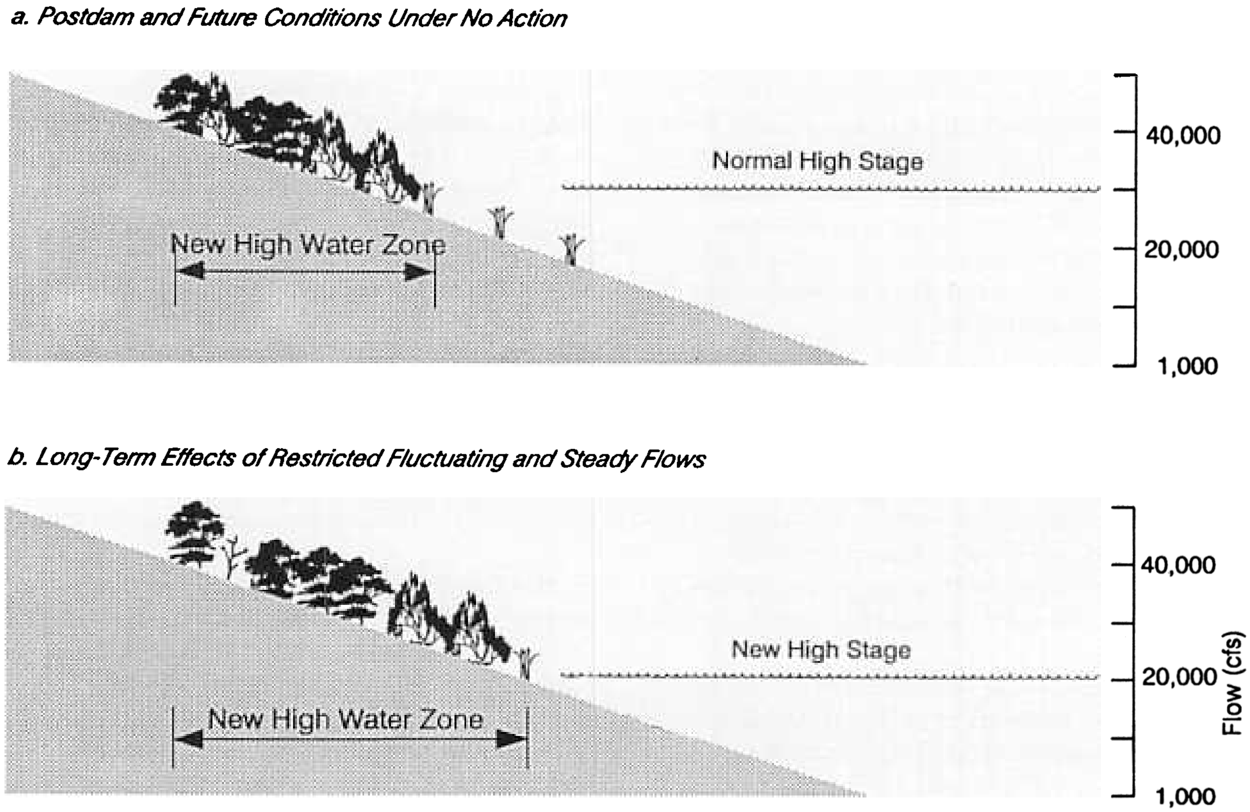


Figure IV-14.— Area coverage of woody plants would increase under alternatives with reduced maximum flows, and species composition would stabilize into similar patterns in the long term. Some mortality of woody plants may occur at upper elevations of the NHWZ under alternatives with reduced maximum flows. However, changes in species composition (and area) depend on site-specific characteristics and cannot be estimated.

least one major flood event is assumed to occur between 20 and 50 years following implementation. A flood occurring early in the long-term period of analysis would give vegetation up to 30 years to recover, while a flood later in the period would permit less time for recovery. Although the timing of a flood event cannot be predicted, it is assumed that enough time would be available between a major flood and the end of the long-term period of analyses for vegetation to recover to a level similar to baseline conditions under these two alternatives.

Although the magnitude and duration of a major flood event cannot be predicted, the effects on downstream vegetation are expected to be similar to those described in chapter III. Major (discharges above 45,000 cfs), uncontrolled (lasting longer than 1 month) floods return riparian zones to earlier successional stages. In general, vegetation initially would be lost (up to 50 percent at some sites in 1983) through scouring, drowning, or burial beneath sediment. After floodwaters recede, sediment redistributed by floodflows would be available for plant expansion. Since vegetation returned to 75 percent of 1982 levels in less than 10 years (Stevens and Ayers, 1993), it is assumed that riparian vegetation would return to preflood conditions within 10 to 15 years.

Effects of uncontrolled flood releases are independent of daily dam operations and would be similar to effects described in chapter III, regardless of future dam operations. Because of the assumed similarity in effects between historic and future floods, uncontrolled floods are not addressed under each alternative. This lack of treatment, however, should not be interpreted as a statement on the lack of importance of uncontrolled floods in the dynamics of riparian plant communities. Major high flow events affect processes and "reset" ecosystem component levels, and—at least for riparian vegetation—can be defined as the single most important system event affecting this resource. However, once reset, riparian vegetation is again defined by daily operations.

It is assumed that water levels in Lakes Powell and Mead would rise during the short-term period of analyses and approach or reach full reservoir capacities. Lake levels are assumed to depend on regional water supply, which is dictated by climatic conditions. Rising lake levels would affect riparian vegetation that has developed during several years of low lake levels following the high flow years of 1983-86. This is especially true for Lake Mead. As Lake Mead fills, riparian vegetation would be inundated and its nutrients recycled into the aquatic system. With another dry cycle, lake levels would recede and riparian vegetation would again increase.

The effects of changing lake levels on riparian vegetation are assumed to be similar under different dam operations and are discussed here and not under each alternative. Plants develop on delta deposits that are exposed during prolonged periods of low reservoir levels (see discussion of deltas under SEDIMENT in chapters III and IV). Cycles of low reservoir levels followed by full reservoir levels would continue into the long term. Vegetation would flourish during low reservoir periods. As Lake Mead fills, vegetation would be inundated and disappear, and nutrients would be recycled into each lake's aquatic system.

As lake levels inundate vegetation, the presence of plants causes additional sediment to aggrade deltas. Major flood events would enhance aggradation by permitting higher flows to build higher deposits. At some point in delta formation, high floodflows would aggrade sediment deposits behind the delta crest to an elevation equal to full reservoir water level. Deposits at full reservoir levels would become permanently vegetated after floodwaters recede.

The time required for delta aggradation to reach full reservoir level is unknown but is assumed to be longer than 50 years. Therefore, riparian plants supported by Lake Mead would tend to increase area coverage under all alternatives. However, it should be noted that during this long-term trend of increasing vegetation, riparian plants would disappear periodically during the processes of delta formation.

One of the proposed flood frequency reduction measures would raise the spillway gates at Glen Canyon Dam an additional 4.5 feet, increasing Lake Powell's potential surface acres by 2 percent. If implemented and ultimately used, this measure could result in infrequent and temporary flooding of riparian vegetation currently above Lake Powell's full pool elevation of 3700 feet. If such temporary flooding occurred, it would cause no adverse effects to plants; short-term inundation may even benefit these riparian plant communities.

Emergent Marsh Plants

Short-term responses of emergent marsh vegetation to certain common elements of the proposed alternatives are difficult to predict. Under baseline (no action) conditions, 95 percent of wet marsh vegetation would exist in a fluctuating flow zone between stages equivalent to 10,000 and 20,000 cfs. Elements such as flood frequency reduction measures, reduced maximum flows, habitat maintenance flows, and beach/habitat-building flows would create quite different conditions under some alternatives.

Reduced flood frequency and reduced maximum daily and/or seasonal flows would create dryer conditions for some patches of emergent marsh plants that historically have been supported by regular patterns of inundation. However, plants such as cattails can persist without inundation for extended periods—perhaps years. These patches of emergent marsh plants would be replaced by woody plants while others would develop at suitable sites made available by reduced flows.

The exact total area or number of patches of emergent marsh vegetation that would develop or be supported under each alternative cannot be predicted because the area suitable for marsh plants (sites providing both water and appropriate soil/nutrient composition) is unknown. Future suitable sites are either under water or have not yet formed. However, the response of vegetation to the interim flows implemented in 1991 indicates that marsh plants will rapidly develop in suitable sites exposed at lower elevations.

No data exists at this time to indicate that either fluctuating or steady flow patterns would support more or fewer areas of marsh plants than no action conditions. However, it is assumed that fluctuating flow alternatives would more closely mimic the No Action Alternative than would steady flow alternatives. It is further assumed that, because steady flows would wet a smaller area than fluctuating flows, steady flows would support fewer patches and smaller areas of emergent marsh plants. To help readers evaluate changes among baseline patches of marsh plants and the alternatives, a qualitative evaluation of changes to aggregate area of wet marsh plants relative to no action is provided. For example, when compared to no action conditions, the aggregate area of wet marsh plants under the action alternatives would either be the same as, same to less than, or less than no action conditions.

Two alternatives—seasonally adjusted and year-round steady flows—would affect water levels in Lakes Powell and Mead seasonally in any water year. Elevation changes for both lakes would be within historic average annual fluctuations, with generally lower high elevations and higher low elevations for Lake Powell and higher water levels during the growing season for Lake Mead. Any differences in annual responses between these alternatives and others would be overridden by the cyclic effects of regional weather patterns as described above.

Summary of Impacts: Vegetation

Alternative operations of Glen Canyon Dam would affect riparian vegetation within the river corridor in several different ways during the short-term (5 to 20 years) period of analyses. First, reduced frequency of major uncontrolled flood releases would result in an unknown, but assumed equal, decline in area coverage of riparian vegetation in the OHWZ under all alternatives. Some species found in the OHWZ would expand into the NHWZ to become an important part of this plant community. As vegetation shifts from riparian to desert shrub, the OHWZ may disappear as a distinct zone of vegetation sometime in the distant future beyond 50 years.

Second, because of higher maximum flows than no action, the Maximum Powerplant Capacity Alternative would result in reduced area of riparian vegetation in the NHWZ.

Third, under no action, woody plants within the NHWZ would be maintained within stage boundaries equivalent to flows between about 22,000 and 40,500 cfs. Species composition would continue to develop toward an undefined equilibrium. Periodic inundation, in patterns similar to existing conditions, would permit continued maintenance of emergent wet marsh vegetation at sites currently occupied (stage elevations equivalent to 10,000 to 20,000-cfs flows).

The restricted fluctuating and steady flow alternatives all would permit riparian vegetation to expand into sites created by reduced maximum flows (table IV-10). Area coverage of woody plants in the NHWZ would increase (figure IV-13). Some new establishment of emergent marsh plants would occur at the mouths of return-current channels and other suitable sites. Patches of emergent marsh plants that lose their water supply would be dominated by woody plants and disappear.

The Moderate and Modified Low Fluctuating Flow Alternatives and the Seasonally Adjusted Steady Flow Alternative include habitat maintenance flows. Maintenance flows are assumed to affect the area available for vegetation, but the magnitude of effect is unknown. The boundaries of potential area change, based on active width of unstable sandbars, are presented

Table IV-10.—Summary of anticipated impacts on VEGETATION during the short-term period of analysis by alternative

VEGETATION	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
	Undetermined reduction	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action
New high water zone[1]	No net change	0 to 9% reduction	15 to 35% increase	23 to 40% increase	30 to 47% increase	30 to 47% increase	45 to 65% increase	38 to 58% increase	63 to 94% increase
With habitat maintenance flows				0 to 12% increase	0 to 12% increase			0 to 12% increase	
Species composition	Tamarisk and others dominate	Tamarisk and others dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate
Emergent marsh plants New high water zone Aggregate area of wet marsh plants[2]	No net change	Same as no action	Same as or less than no action	Same as or less than no action	Same as or less than no action	Same as or less than no action	Less than no action	Less than no action	Less than no action
Lake woody and emergent marsh plants (area)	Undetermined increase	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action

[1] Potential area change based on change in width of unstable sandbars as compared to no action conditions. Percent changes are useful for relative comparisons among alternatives in that not all area made available would be suitable for plant growth. The assumed relationship between sandbar stability and vegetation coverage is based on observations during historic and interim operations but has not been tested.

[2] Area coverage of emergent marsh vegetation under the various alternatives cannot be predicted but would likely be similar, and new patches of marsh plants would establish at the maximum discharge stage.

in table IV-10. It is assumed that the actual area change in woody vegetation would occur between these two estimates.

Species composition of woody plants in the NHWZ would change during the short term under alternatives with lower maximum flows. New areas of sediment would be exposed and, thus, available for plant growth. Species that can reproduce by way of subsurface tubers or runners would have an advantage. Coyote willow, arrowweed, camelthorn, and other plants have expanded over beaches since the high flows of 1983-86, and this trend would continue on sediment exposed by reduced flows.

Changes in species composition also are likely in the upper elevations of the NHWZ under restricted fluctuating and steady flow alternatives. Drier conditions would favor mesquite and other species over tamarisk and willow. Some mortality would likely occur as plants adjust to a new water regime. Willow would disappear first, with tamarisk persisting for some time. While it is unlikely that the NHWZ would expand above its current limit (about 40,500-cfs stage), whether it maintains its current upper boundary through species composition changes or retreats downslope through plant mortality is dependent on site-specific characteristics and cannot be quantified.

Beach/habitat-building flows would be used for major restructuring of sediment deposits. These flows would interrupt, disturb, and reset plant succession in the riparian community. Some woody vegetation would be buried and lost as sand is deposited on high elevation sandbars, and patches of emergent marsh plants would be lost through scouring or burial as return-current channels are restructured. Both woody plants and emergent marsh vegetation would develop at suitable new sites in the years following beach/habitat-building flows. These flows would impart a dynamic quality to sediment deposits, and sandbars would be characterized by periodic changes in the combination of vegetation and open bare areas. A mixture of riparian vegetation and bare sand provides habitat diversity for both wildlife and recreationists.

In the long term (20 to 50 years), differences among alternatives would continue to develop. First, the No Action and Maximum Powerplant Capacity Alternatives are assumed to include at least one major flood event. Riparian vegetation would be set back to an earlier successional stage. However, woody and emergent marsh plants would recover postflood to a level comparable to baseline conditions.

The remaining action alternatives include flood frequency reduction measures throughout the long-term period of analyses. This protection would permit riparian development to follow trends begun in the short term. Habitat maintenance and beach/habitat-building flows would maintain woody and emergent marsh plants that would develop during the short term. All alternatives with flood protection would support increases in coverage of woody plants at the end of the long-term period of analyses (figure IV-14). Dryer conditions in the upper elevations of the NHWZ would shift species composition from tamarisk and willow to mesquite and other plants. Tamarisk, willow, and other plants would be favored downslope at wetter sites.

Finally, riparian vegetation supported by Lake Mead would increase in area coverage by an unknown but assumed equal amount under all alternatives. Delta formation processes would support this long-term trend by periodically inundating and killing plants during periods of high reservoir elevations and floodflows. During periods of inundation, additional sediment would be deposited on delta formations, thus increasing their elevation. At some time in the distant future (beyond 50 years), through numerous cycles of low reservoir elevations and vegetation reestablishment followed by high floodflows, high reservoir elevations, and no vegetation, delta deposits would reach full pool elevation and become permanently vegetated. This process has begun (figure III-25) and will continue as long as high flows occur while Lake Mead is full.

Unrestricted Fluctuating Flows

No Action Alternative

Analyses of effects to riparian vegetation under no action conditions in the short term basically project existing trends. In the long term, it is assumed that at least one major uncontrolled flood event would affect riparian vegetation.

Woody Plants. Vegetation within the NHWZ is expected to continue to develop as described under existing conditions (see chapter III, VEGETATION) and would occupy the same sites at stage elevations equivalent to flows between 22,000 to 40,500 cfs. However, without flood control, riparian plant development would recycle following a major uncontrolled flood event. The effects on riparian vegetation from a major flood event are assumed to be similar to those reported by Stevens and Waring (1986) following the 1983 floodflows.

Because timing cannot be predicted, a flood event was assumed in the long term. This time span would permit vegetation to recover to a level similar or identical to baseline conditions. A flood event late in the analysis period would permit less recovery and, therefore, would mean a larger difference between no action conditions and the action alternatives with flood protection.

The composition of woody plants within the riparian corridor (exclusive of the OHWZ) would follow trends described in chapter III, with coyote willow, arrowweed, honey mesquite, and other species increasing in abundance.

Emergent Marsh Plants. Under the No Action Alternative, dry marsh plants would continue to expand into remaining sites suitable for their germination and growth. Thus, patches of dry marsh vegetation initially would increase in both numbers of patches and coverage until all suitable sites are occupied. Concurrently, but at a slower rate, woody vegetation would continue to expand into suitable sites. Patches of dry marsh plants on higher sites in the NHWZ would be susceptible to woody plant expansion. As shading from woody plants increases, emergent marsh plants would be eliminated. Thus, until a major uncontrolled flood event occurs, dry marsh vegetation may gradually decline by an unknown number of patches and area coverage.

Wet marsh species such as cattails and rushes have expanded into most of the suitable sites under historic conditions; any future expansion would be expected in area coverage at existing patches of wet marsh vegetation. Fluctuating flows would continue to carry sediment into return-current channels and other sites where lower water velocities permit deposition. With time (and without a major flood event or beach/habitat-building flows), these sites would fill with sediment and permit expansion of woody vegetation into them.

As with woody vegetation, it is assumed that a future major flood would greatly reduce existing patches of both dry and wet marsh vegetation before they are replaced by woody plants. However, timing of the assumed flood would permit recovery of emergent marsh plants, by the end of 50 years, to levels comparable to baseline conditions. Only wet marsh plants are treated in subsequent analyses as emergent marsh plants.

Maximum Powerplant Capacity Alternative

Because maximum flows under this alternative are higher than those under no action, the area occupied by **woody plants** would be reduced in some reaches. An area of beach up to 5 feet wide (or 0 to 9 percent of the width of unstable sandbars under no action) would become active and unstable in some reaches under this alternative; other reaches would experience no measurable changes. It is assumed that vegetation occupying unstable sites would be lost through erosion.

Under this alternative, an area between stages equivalent to 31,500 and 33,200 cfs would be inundated periodically—a 5-percent increase in maximum flow over no action. Patches of **emergent marsh plants** are limited above the 31,500-cfs stage, and abundance and distribution of this resource would be similar to no action conditions.

No beach/habitat-building flows would occur under this alternative. As with woody vegetation, it is assumed that a major flood would greatly reduce existing patches of marsh plants before they are replaced by woody plants. However, timing of the assumed flood would permit recovery of emergent marsh vegetation, by the end of 50 years, to levels comparable to no action conditions.

Restricted Fluctuating Flows

Daily flow fluctuations would affect vegetation through two processes:

- Deposition and erosion of sediments serving as substrate
- Changes in river stage

The effects of alternative operations discussed below are presented in terms of the flow patterns anticipated during a minimum release year (8.23 maf). Based on historic data, minimum release years would occur about 40 to 50 percent of the time. During moderate or high water years, total area coverage of riparian vegetation may be reduced. Under a fluctuating release pattern, riparian vegetation under the High, Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives would be affected by higher water volumes because of increases in maximum stages. Higher flows would tend to shift conditions, including the active width of unstable sandbars, toward those under the No Action Alternative. The amount of reduction in riparian vegetation would depend on the magnitude and frequency of discharges and subsequent deviation from the patterns described below.

High Fluctuating Flow Alternative

The area available for expansion of **woody plants** (as represented by the difference between unstable bar width for no action and this alternative) would increase an average of 10 to 15 feet (15 to 35 percent) over no action throughout the 11 river reaches in the study area.

Because of flood control measures, plant species composition in the NHWZ would be somewhat different than under no action. Tamarisk would be concentrated near the maximum discharge stage, with honey mesquite and other native species occupying higher NHWZ elevations. Coyote willow and arrowweed would occupy sandy sites. **Emergent marsh plants** would continue to occupy current sites or expand in the short term.

Beach/habitat-building flows would maintain the above pattern. Depending on the timing of these flows, either tamarisk, native plants, or both would germinate on suitable wetted sites. With a return to normal flow patterns, native plants would dominate. New sites suitable for emergent marsh plants would be maintained or created in the short term.

Moderate Fluctuating Flow Alternative

Habitat maintenance flows under this alternative would affect **woody plants** to an unknown degree. The area available for plant expansion would approach, but be less than, the area available for expansion under identical flow patterns that do not have annual maintenance flows. Three considerations are involved in this prediction.

First, without modifications from maintenance flows, the potential maximum area available for expansion by woody plants on stabilized sandbars in each river reach would increase an average of 15 to 26 feet (23 to 40 percent) over no action.

Second, sediment transported by maintenance flows initially would bury some vegetation to an unknown extent. However, the maximum estimate is that all areas up to an elevation equivalent to the 30,000-cfs stage could be affected. Those areas unaffected by maintenance flows would average (by river reach) a 0- to 5-foot increase (0 to 12 percent) over no action conditions. Because of the limited magnitude and duration of these flows, it is assumed that not all vegetation would be buried.

Finally, species that tolerate burial would eventually grow through new deposits and join those plants that are not buried to expand the areas of woody plants. The relationships between discharge, sediment, and woody plants would probably require several years to stabilize to the point where plants are no longer buried by maintenance flows.

Vegetation within the NHWZ would be affected by reductions both in active width of sandbars and maximum stage under this alternative. A zone between 22,300 and 31,500 cfs would no longer be regularly inundated during minimum release years, except during maintenance flows. Coupled with flood control, this would result in dryer conditions dictating plant species composition in the NHWZ. Young tamarisk would be concentrated near the 22,300-cfs stage. Coyote willow, arrowweed, and other species would expand from higher elevations in the NHWZ to suitable sites at lower elevations. Willow and arrowweed would continue to expand on high sand deposits.

Emergent marsh plants initially would occupy historic sites and expand into suitable sites created by lower maximum flows. Patches above the stage equivalent to 22,300 cfs would no longer be subject to frequent inundation. These dry sites eventually would fill with sediment transported by habitat maintenance flows and be lost. A 29-percent reduction in maximum stage would create or make available additional marsh plant sites. Aggregated sites may equal or be less than the area of emergent marsh plants under no action conditions.

Habitat maintenance flows would support this plant pattern until some other flow regime occurs. The higher discharges of periodic beach/habitat-building flows would likely disrupt any stability that would develop among sediment, plants, and maintenance flows. After a beach/habitat building flow, a new level of stability would become established and continue until the next high flow event. It is assumed that beach/habitat-building flows would also restructure return-current channels important for marsh plants below the 20,000-cfs stage.

Modified Low Fluctuating Flow Alternative

Habitat maintenance flows under this alternative would result in effects on **woody plants** similar to those discussed under the Moderate Fluctuating Flow Alternative. The area available for woody plant expansion would be between the potential maximum area of stabilized sandbars—21 to 31 feet (30 to 47 percent) over no action—and the area of sandbars unaffected by maintenance flows—0 to 5 feet (0 to 12 percent) over no action. The increase in woody plants would likely approach, but be less than, the potential maximum area of stabilized sandbars under this alternative.

A zone between 20,000 and 31,500 cfs would no longer be inundated during minimum release years, except during habitat maintenance flows. This change, along with flood control, would result in dryer conditions that would dictate plant species composition in the NHWZ. These changes in species composition would be similar to those discussed under the Moderate Fluctuating Flow Alternative.

Emergent marsh plants would respond to changes in discharge similarly to the Moderate Fluctuating Flow Alternative. Patches above the stage equivalent to 20,000 cfs would no longer be subject to frequent inundation and would disappear. A 37-percent reduction in maximum stage would create or make available additional marsh plant sites. Aggregated sites may equal or be less than the area of emergent marsh plants under no action conditions.

Habitat maintenance flows would support this plant pattern until disrupted by a beach/habitat-building flow as discussed under the Moderate Fluctuating Flow Alternative. After a beach/habitat-building flow, a new level of stability would develop among sediment, riparian vegetation, and maintenance flows.

Interim Low Fluctuating Flow Alternative

The assumed area available for expansion by **woody plants** in the short term represents an increase of 21 to 31 feet (30 to 47 percent) over no action. Also, a zone between 20,000 and 31,500 cfs would no longer be inundated by fluctuating flows during minimum release years. Young tamarisk would be concentrated near the 20,000-cfs stage. Coyote willow, arrowweed, and other species would expand from higher elevations in the NHWZ to suitable sites at lower elevations. Willow and arrowweed would continue to expand on high sand deposits.

Emergent marsh plants would continue to occupy historic sites and expand into suitable sites created by lower maximum flows. Patches above the stage equivalent to 20,000 cfs would no longer be subject to frequent inundation and would disappear. A 37-percent reduction in maximum stage would create or make available additional sites suitable for marsh plants. This prediction is consistent with plant responses to interim flows conditions. Aggregate area of wet marsh plants would be the same as or less than no action.

Beach/habitat-building flows would maintain this plant pattern in the short term. While such flows could be timed to coincide with seed release of several different plants, it is assumed that tamarisk would be the dominant colonizer on suitable sites made available by reduced flows. However, based on observations since the 1983-86 floodflows, native plants would quickly become established and even have an advantage at newly deposited sand beaches. Beach/habitat-building flows would also maintain return-current channels important for marsh plants below the 20,000-cfs stage.

Steady Flows

The effects of steady releases on the indicators of vegetation resources would depend on stage and duration of flows. Stages lower than historic conditions would encourage expansion of woody plants into suitable sites at lower elevations (figure IV-15).

Future responses of emergent marsh plants to steady flows are unknown. Lower maximum stages would dry out patches of wet emergent marsh plants, while higher steady flows for extended periods may result in scouring or drowning of some plants. However, the following analyses are based on the same assumptions applied to all alternatives with reduced maximum stages. These assumptions, plus beach/habitat-building flows (and habitat maintenance flows under the Seasonally Adjusted Steady Flow Alternative), indicate aggregate area coverage of marsh plants would be less than under the No Action Alternative.

During moderate and high water years, the release patterns identified for steady flow alternatives could not be maintained. The Seasonally Adjusted and Year-Round Steady Flow Alternatives would resemble the Existing Monthly Volume Steady Flow Alternative as releases increased. In high release years, all three steady flow alternatives would have high steady flows for extended periods, with a reduction in riparian vegetation from scouring and drowning.

In the long term, alternatives with reduced maximum flows would exhibit shifts in location of riparian plants in the NHWZ, including both replacement by plants requiring less moisture in higher elevations and expansion into suitable sites at lower elevations. These changes have been described for fluctuating flows and are assumed to be equally applicable to steady flow alternatives.

Existing Monthly Volume Steady Flow Alternative

Vegetation in the NHWZ would be affected by both a reduction in active width of sandbars and a reduction in maximum stage under conditions of this alternative. The area available for expansion by **woody plants** represents an average increase of 26 to 41 feet (45 to 65 percent) over no action conditions.

A zone between about 16,300 and 31,500 cfs would no longer be periodically inundated by fluctuating flows. Tamarisk would be

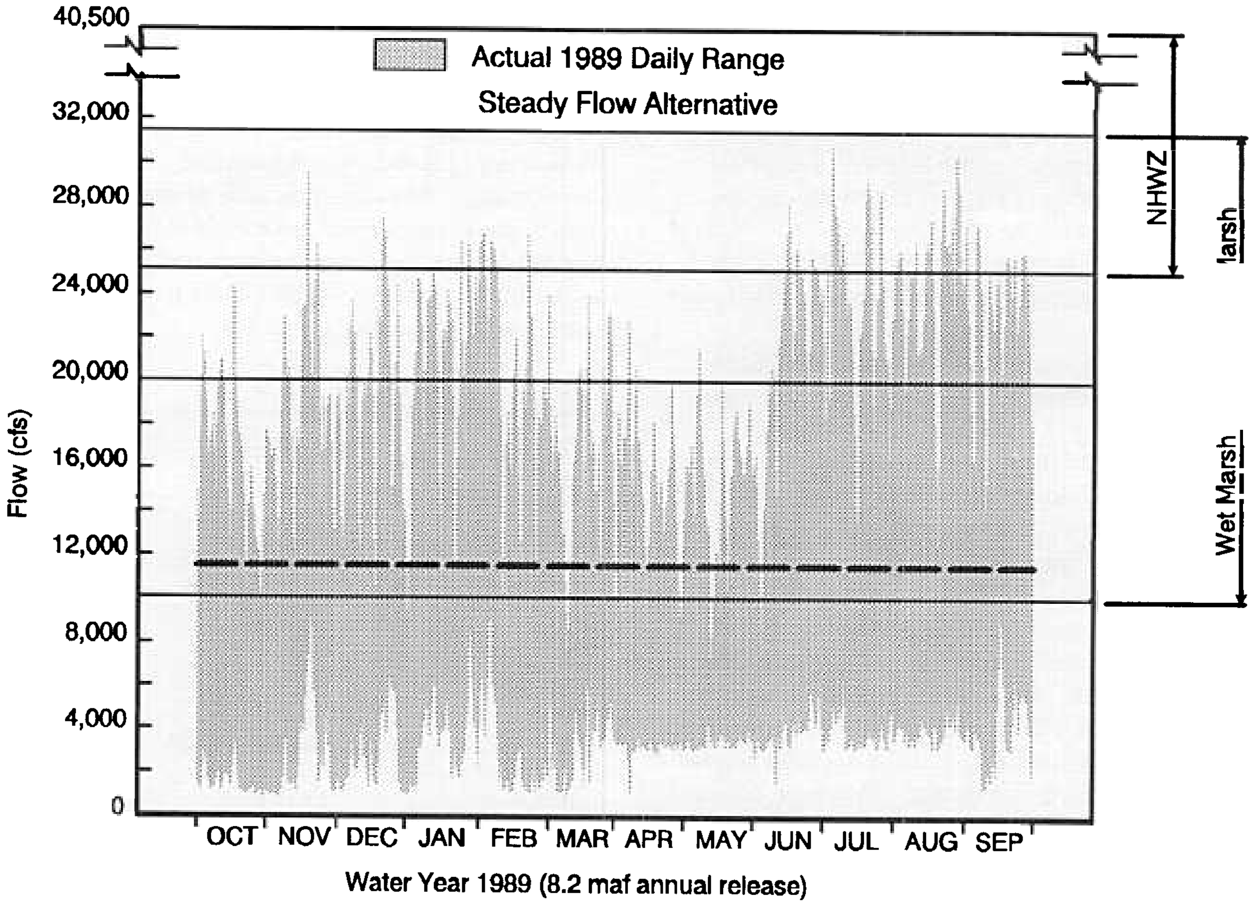


Figure IV-15.—Because of reduced maximum flows under some alternatives, area coverage of woody plants in the new high water zone would increase. The potential for increase is greatest under the Year-Round Steady Flow Alternative.

concentrated near the 16,300-cfs stage. Honey mesquite and other species would expand from higher elevations into the NHWZ, and coyote willow and arrowweed would occupy sandy sites.

Under this alternative, **emergent marsh plants** would be subjected to steady flows that varied monthly. Marsh plants above the 16,300-cfs stage would lose their water supply and be lost. Reduced stage would create or make available additional sites suitable for marsh plant development. Aggregated sites supporting wet marsh plants would equal a smaller area than under no action conditions.

Seasonally Adjusted Steady Flow Alternative

Habitat maintenance flows under this alternative would result in effects on **woody plants** similar to those discussed under the Moderate Fluctuating Flow Alternative. In the 11 river reaches, the area available for this expansion would be between the maximum area of stabilized sandbars—26 to 36 feet (38 to 58 percent) over no action, and the area of sandbars unaffected by maintenance flows—0 to 5 feet (0 to 12 percent) over no action. The increase in woody plants would likely approach, but be less than, the potential maximum area of stabilized sandbars under this alternative.

An area between 18,000 and 31,500 cfs would no longer be regularly inundated, except during annual habitat maintenance flows. This reduction in maximum stage, together with flood control, would result in dryer conditions dictating plant species composition in the NHWZ. Tamarisk would be concentrated near the 18,000-cfs stage. Honey mesquite and other species would expand from higher elevations into the NHWZ. Coyote willow and arrowweed would occupy sandy sites.

Under this alternative, **emergent marsh plants** would either completely lose their water supply for 5 months (8,000-cfs flows), be partially inundated for 5 months, or completely inundated for 2 months (along with a 1- to 2-week period of inundation to 30,000 cfs during maintenance flows). The responses of patches of marsh plants to this variable water regime are difficult to predict. For example, some patches would experience inundation in May and June (a critical growth period), while drying would occur in August through December. Reduced stage would create or make available additional sites suitable for marsh plant development. However, all sites would aggregate to an area less than the area of emergent marsh plants under no action.

It is assumed that stage reduction would affect woody riparian plants as described above for the long-term period of analyses. The abundance of mesquite and other plants would be influenced by beach/habitat-building flows. The NHWZ would maintain the increase in overall area coverage described for the short term.

Year-Round Steady Flow Alternative

The area available for expansion by **woody plants** represents an average increase of 36 to 57 feet (63 to 94 percent) over no action. During a minimum release year, a zone between 11,400 and 31,500 cfs would no longer be inundated by fluctuating discharges. Such changes are quite different from the No Action Alternative. Changes in woody plant species composition are assumed to be similar or identical to those predicted under the Seasonally Adjusted and Existing Monthly Volume Steady Flow Alternatives.

A reduction in maximum discharge would affect area coverage of **emergent marsh plants**. Any marsh plants below the 11,400-cfs stage would be permanently inundated and presumed lost. Reduced stage (64 percent) would create or make available additional sites suitable for marsh plant development. However, because of the limited area wetted by a year-round steady flow, the aggregate area of emergent marsh vegetation under this alternative would be less than that supported by no action conditions.

WILDLIFE AND HABITAT

Issue:

How do dam operations affect area WILDLIFE AND their HABITAT?

Indicators:

Area of **woody and emergent marsh plants** for wildlife habitat
Abundance of **aquatic food base** for wintering waterfowl

This section addresses the effects of alternatives on terrestrial wildlife other than special status species. Very little wildlife population data exists for either the predam or postdam habitats found along the river corridor. However, it is assumed that almost all wildlife concerns can be addressed by considering the effects on wildlife habitat as represented by riparian vegetation.

Many species use woody plants directly as nest sites or cover or, in the case of beaver and others, use some plants as food. Other species, such as waterfowl, nest in emergent marsh plants and other suitable sites. Riparian vegetation also provides cover for insects important as food for mammals, birds, and amphibians and reptiles (herpetofauna). Therefore, no specific analyses of impacts on individual wildlife species were conducted for each alternative. Instead, it is assumed that changes in area coverage of riparian vegetation are directly linked to changes in riparian wildlife habitat.

One notable wildlife resource does not fit the above pattern. Waterfowl are attracted in winter to the Colorado River below Glen Canyon Dam by open water and the food it provides. While various species feed on different foods, it is assumed that *Cladophora* can be used as an index of food availability for wintering waterfowl. *Cladophora* and associated diatoms serve as food as well as cover for macroinvertebrates such as *Gammarus*, chironomid and simuliid larva, and others. Like the analyses presented in the FISH section, *Cladophora* is used here as an indicator of the aquatic food base available to wintering waterfowl.

This analysis of riparian habitat, as based on riparian vegetation, generally is limited to the river corridor between the dam and Separation Canyon (although only data to Diamond Creek are available). It is assumed that dam operations affect vegetation and, in turn, habitat through two processes—the dynamics of beach aggradation and degradation and prolonged change in river stage (see WATER, SEDIMENT, and VEGETATION in this chapter). Together, these processes are reflected as changes in area coverage of woody plants and, to a lesser degree, changes in species composition. These changes affect habitat suitability for area wildlife.

Analysis Methods

During the short-term period of analysis, it is assumed that changes in wildlife habitat would closely follow changes in riparian vegetation, which would follow changes in exposed sediment deposits resulting from daily water release patterns. Infrequent releases above the maximum flow identified for each alternative, habitat maintenance flows, and beach/habitat-building flows of unknown stage may occur in the short term. Additional impacts resulting from these sources are identified where appropriate. Daily dam operations also would affect food for wintering waterfowl during the short-term period of analysis.

Major uncontrolled flood events are expected under only two alternatives during the long-term period of analyses: the No Action and Maximum Powerplant Capacity Alternatives. Flood events would affect vegetation and, in turn, habitat in ways previously described (see chapter III, VEGETATION). Habitat and its value to wildlife would be reduced until replaced through natural succession of vegetation. Most wildlife populations are resilient and able to adapt to cycles of habitat abundance. However, a few species with small populations could experience adverse impacts from flood-related reductions in habitat. These species have special status and are treated in another section (see ENDANGERED AND OTHER SPECIAL STATUS SPECIES in this chapter).

Woody and Emergent Marsh Plants

Changes in area of emergent marsh plants resulting from implementation of any of the alternatives would depend largely on changes in river stage and duration of flows. Most patches of marsh plants occur in the NHWZ and are maintained by a water release pattern that alternately floods and then exposes them. Changes in this pattern would result in changes in area coverage of marsh plants and the habitat value of these sites.

It is assumed that Lakes Powell and Mead would cycle through periods of low and high water levels during both the short- and long-term periods of analyses. As described under VEGETATION, riparian vegetation that develops during low lake level periods would be lost and develop again (recycle) as lake levels increase and then decrease. Vegetation supported by low lake levels is important habitat for many species, especially breeding birds. Increases and decreases in habitat area would depend on regional water conditions and are, therefore, independent of all alternatives.

Aquatic Food Base

Most wintering waterfowl use occurs in the upper reaches of the river, while *Cladophora* abundance generally is highest between the dam and Lees Ferry. Over 90 percent of the 2,780 waterfowl surveyed in January 1991 were observed between the dam and the LCR (Kline, written communication, 1992). Evaluation of effects on the aquatic food base is limited to wetted perimeter data from two sites: one near the dam and one near Lees Ferry (see FISH in this chapter). Comparisons made from these data are useful in evaluating relative differences between no action and action alternatives.

The specific effects of a major flood event on *Cladophora* and the associated aquatic food base are unknown. It is reasonable to assume, however, that effects would not be irreversible, since the *Cladophora* population survived the high flows of 1983-86.

Summary of Impacts: Wildlife and Habitat

In general, individual animals would not be directly affected by daily operations of Glen Canyon Dam. For example, mammals, birds, herpetofauna, and invertebrates occupying or using riparian habitat generally are mobile and would move as required by daily fluctuations. Birds using the riparian zone as a travel lane through Grand Canyon would not be directly affected by any of the alternatives. However, those species that nest in riparian vegetation would be indirectly affected by changes in area coverage of plants. In the short term, woody plant coverage, and therefore riparian habitat, would increase under most alternatives. Emergent marsh plants would either remain similar in coverage to no action or decrease.

A summary of impacts on wildlife and habitat, based on impacts to either riparian vegetation or the aquatic food base, is presented in table IV-11.

Alternative Glen Canyon Dam operations would affect riparian vegetation, and therefore habitat, in several different ways during the short-term (5 to 20 years) period of analysis. Briefly, all alternatives would contribute to the gradual decline of the OHWZ. No action would maintain the existing riparian vegetation area, while the Maximum Powerplant Capacity Alternative would create conditions leading to a decline in habitat area. The remaining alternatives would permit woody riparian vegetation to expand, in differing amounts, into sites created by reduced maximum flows.

Although no data are available on habitat patch size along the river corridor, it is assumed that as area of woody riparian vegetation increases so too will habitat and patch size. The ecological value of habitat to wildlife is, in part, also related to the patch size of a vegetated area. In order for a patch of habitat to be valuable to mammals, breeding birds, herpetofauna, or invertebrates, it must be large enough to provide adequate food resources and shelter. For example, larger patch sizes are likely to have a greater number of bird species present. Wilson and Carothers (1979) tested this hypothesis in Grand Canyon and determined that as habitat patch size decreased, bird species diversity and density were similarly reduced. As patch size increased, additional species were found to occur within the habitat.

An annual habitat maintenance flow is included in the Moderate and Modified Low Fluctuating Flow Alternatives and the Seasonally Adjusted Steady Flow Alternative in order to move and deposit sediment higher than would be possible under daily flow patterns. As discussed under VEGETATION (earlier in this chapter), some vegetation would be buried by initial maintenance flows, and thus its value as habitat reduced. Vegetation that is not buried or that grows up through new deposits would be unusable to area wildlife during the period of inundation.

In the long-term period of analyses (20 to 50 years), differences among alternatives would continue to develop. At least one major flood is assumed to occur under the No Action and Maximum Powerplant Capacity Alternatives. Succession of riparian vegetation would be set back to an earlier stage due to loss of plant coverage. However, it is assumed that woody and emergent marsh plants ultimately would recover to a level comparable to no action conditions.

The restricted fluctuating and steady flow alternatives include flood frequency reduction measures. This flood protection would permit riparian development following trends begun in the short

Table IV-11.—Anticipated impacts to indicators of WILDLIFE AND HABITAT during the period of short-term analysis by alternative

WILDLIFE AND HABITAT	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Woody plants[1] (area)									
Old high water zone	Undetermined reduction	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action
New high water zone									
Sandbar stability	No net change	0 to 9% reduction	15 to 35% increase	23 to 40% increase	30 to 47% increase	30 to 47% increase	45 to 65% increase	38 to 58% increase	63 to 94% increase
With habitat maintenance flows				0 to 12% increase	0 to 12% increase			0 to 12% increase	
Species composition	Tamarisk and others dominate	Tamarisk and others dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate	Tamarisk, coyote willow, arrowweed, camelthorn dominate
Emergent marsh plants									
New high water zone									
Aggregate area of wet marsh plants	No net change	Same as no action	Same as or less than no action	Same as or less than no action	Same as or less than no action	Same as or less than no action	Less than no action	Less than no action	Less than no action
Woody and emergent marsh plants (area) in Lakes Powell and Mead	Undetermined increase	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action
Aquatic food base[2] (for wintering waterfowl)	Stable	Same as no action	Same as no action	Potential increase	Potential increase	Potential increase	Potential increase	Potential increase	Potential increase

[1] See chapter IV, VEGETATION for a description of analysis assumptions.
[2] See chapter IV, FISH for a description of analysis assumptions.

term. All alternatives with flood control would support increases in woody plant coverage at the end of the long-term period of analysis.

Dryer conditions in the upper elevations of the NHWZ would favor a shift from tamarisk and willow to mesquite and other plants. Willow—which is less drought resistant—would disappear first, with tamarisk persisting for some time and perhaps arrowweed moving into suitable sites. Tamarisk, willow, and other plants would be favored downslope at wetter sites. Increases in area and diversity of plant species would mean increased habitat.

Beach/habitat-building flows would continue to support existing and expanded coverage of riparian vegetation and changes in species composition initiated in the short term. However, such flows may temporarily reduce the aggregate area of riparian vegetation and, therefore, wildlife habitat (see VEGETATION in this chapter).

Wintering waterfowl would be affected by changes in minimum discharge. The No Action and Maximum Powerplant Capacity Alternatives have a minimum discharge of 1,000 cfs. The remaining alternatives increase minimums from 3,000 to 11,400 cfs. Increased minimum discharges, as well as brief high release periods during habitat maintenance and beach/habitat-building flows, are assumed to benefit the aquatic food base and ultimately wintering waterfowl.

Unrestricted Fluctuating Flows

No Action Alternative

The area of **woody and emergent marsh plants,** and thus riparian wildlife habitat, would remain similar to baseline conditions as described in chapter III.

Cladophora, representing the **aquatic food base,** is limited by minimum reliable flows. Under no action conditions, these flows would be 1,000 cfs, with a wetted perimeter of 580.3 feet near the sampling site at the dam and 380.4 feet at the site near Lees Ferry (see chapter IV, FISH).

Maximum Powerplant Capacity Alternative

Stage change and associated effects on **woody and emergent marsh plants** depend on local channel widths within the fluctuating zone, and thus differ among sites and reaches for the same riverflows. For each reach, an area of beach 0 to 5 feet wide (or 0 to 9 percent of the width of unstable sandbars under no action) would become active and unstable under this alternative. It is assumed that some vegetation, and thus habitat, at affected sites would be lost through erosion.

The Maximum Powerplant Capacity Alternative would have the same minimum flow as the No Action Alternative. Therefore, it is assumed that effects on the **aquatic food base** for wintering waterfowl would be identical to no action conditions.

Restricted Fluctuating Flows

Daily changes in discharge have both positive and negative affects on wildlife habitat. Alternatives with lower maximum discharges would make sites available for expansion of woody plants. Many patches of emergent marsh plants would no longer be inundated on a regular basis. Patches of emergent marsh plants above the maximum discharge stage would receive water only during periods of habitat maintenance and beach/habitat-building flows. These patches of vegetation would temporarily supply structural diversity to the vegetative community but would function as upland vegetation rather than as aquatic plants. These sites would be replaced with woody vegetation.

Sudden deviations from either fluctuating or steady flow patterns, as would occur during habitat maintenance and beach/habitat-building flows, could have temporary adverse effects on ground-dwelling, ground-nesting, and burrowing forms of wildlife including insects, reptiles, and small mammals. The effects on all resources would be considered when scheduling such flows.

High Fluctuating Flow Alternative

Impacts on riparian habitat, including **woody and emergent marsh plants**, would be identical to those described for vegetation. The area of beach available for expansion of woody riparian plants would increase an average of 10 to 15 feet (15 to 35 percent) over no action conditions throughout the study area (see chapter IV, VEGETATION). Emergent marsh plants would continue to occupy historic sites or expand slightly in the short term. The wildlife species that use these plants would respond accordingly.

Increased minimum flows would mean benefits for the **aquatic food base** and, therefore, for wintering waterfowl. Increased minimum flows represent an additional 2,000 cfs of permanent inundation—a 1.5- (Lees Ferry) to 2.0-foot (near the dam) increase in stage and up to an 8.7-foot increase in wetted perimeter over no action.

Moderate Fluctuating Flow Alternative

Woody plants would expand into suitable sites made available by lower maximum flows. The exact extent of expansion is unknown because the relationships between sediment, riparian plants, and habitat maintenance flows are not defined at this time. As was discussed under the analysis of VEGETATION, it is assumed that the area available for woody plant expansion would approach, but be less than, the area available for expansion under identical flow patterns without annual maintenance flows. For this alternative, the upper range of beach widths available for expansion is 15 to 26 feet for the 11 river reaches (a 23- to 40-percent increase over no action conditions). The lower range, or those areas unaffected by maintenance flows, would average a 0- to 5-foot increase (0 to 12 percent) over no action conditions.

Emergent marsh plants would initially occupy historic sites and expand into suitable sites created by lower maximum flows. Patches of marsh plants above the 22,300-cfs stage would no longer be frequently inundated. These sites would be dry, would eventually fill with sediment, and emergent marsh plants would be replaced by woody vegetation. A 29-percent reduction in maximum stage would make additional marsh plants sites available. In aggregate, the area occupied by emergent marsh plants under this alternative would be equal to or less than no action.

Habitat maintenance flows would occur before most wildlife nesting activity. While high flows may temporarily displace some individual animals, maintenance flows would redistribute the sediment critical for riparian plant growth and thus benefit habitat.

Increased minimum flows to (5,000 cfs year-round) would translate into some benefits for the **aquatic food base** and, therefore, wintering waterfowl. Increased minimum flows represent about a 2.4- (Lees Ferry) to 3.5-foot (near the dam) increase in stage and up to a 14.1-foot increase in wetted perimeter.

Modified Low Fluctuating Flow Alternative

Effects on wildlife habitat and wintering waterfowl would be similar to those discussed under the Moderate Fluctuating Flow Alternative. First, the upper range of beach widths available for expansion of **woody plants** is 21 to 31 feet for the 11 river reaches (a 30- to 47-percent increase over no action conditions). The lower range, or those areas unaffected by maintenance flows, would average a 0- to 5-foot increase (0 to 12 percent) over no action conditions.

Second, patches of **emergent marsh plants** above the stage equivalent to 20,000 cfs would lose their source of abundant water, become dry, and eventually fill with sediment. A 37-percent reduction in maximum stage would create or make available additional sites suitable for marsh plants. The aggregate area occupied by emergent marsh plants would be equal to or less than the area supported under no action.

Although the daytime minimum low flow is 8,000 cfs under this alternative, it is assumed that the **aquatic food base** would be limited by the nighttime (and weekend) minimum of 5,000 cfs. This low represents a 4,000-cfs increase over no action conditions and is assumed to represent improved conditions for wintering waterfowl.

This increase equates to a 2.4-foot (Lees Ferry) to 3.5-foot (near dam) increase in stage and up to a 14.1-foot increase in wetted perimeter. It is assumed that the 1- to 2-week habitat maintenance flow included in this alternative would not affect the aquatic food base or disturb wintering waterfowl.

Interim Low Fluctuating Flow Alternative

Habitat for some species would increase under this alternative as **woody plants** in the NHWZ colonize suitable beach sites down to the 20,000-cfs stage. The area of beach available for expansion of riparian habitat would average 21 to 31 feet, or a 30- to 47-percent increase over no action conditions.

A zone between 20,000 and 31,500 cfs would no longer be inundated by fluctuating flows during minimum release years. Combined with flood control, this would result in dryer conditions for NHWZ vegetation, and plants would expand into the fluctuating zone. Young tamarisk would be concentrated near the 20,000-cfs stage, while mesquite and other native species would continue to become established in upper elevations of the NHWZ.

Emergent marsh plants would continue to occupy postdam sites plus expand into suitable sites created by lower maximum flows. Patches above the 20,000-cfs stage would no longer be subject to frequent inundation. Although these sites would be dry, their plant structure would be maintained by periodic beach/habitat-building flows. A 37-percent reduction in maximum stage would create or make available additional sites suitable for marsh plants.

This alternative includes a daytime minimum of 8,000 cfs and a nighttime minimum of 5,000 cfs. For purposes of analyses, the 5,000-cfs minimum is believed to limit *Cladophora* and the **aquatic food base** available to wintering waterfowl. Increased low flows represent an additional 4,000 cfs of permanent inundation over no action conditions. This increase represents a 2.4- (Lees Ferry) to 3.5-foot (near the dam) increase in stage and up to a 14.1-foot increase in wetted perimeter.

Steady Flows

The effects of steady flows on riparian vegetation and wildlife habitat would depend on stage and duration. Stages lower than no action conditions would permit expansion of woody riparian vegetation into suitable sites previously inundated in the fluctuating zone. Lower stages would remove water from emergent marsh plants, while higher steady flows could drown some plants.

Existing Monthly Volume Steady Flow Alternative

Area of riparian habitat for some species would increase under this alternative as **woody plants** in the NHWZ colonize suitable sites down to the 15,000-cfs stage. The area of beach available for expansion of woody riparian plants would range from 26 to 41 feet, or a 45- to 65-percent increase over no action conditions. A zone between about 16,300 and 31,500 cfs would no longer be inundated by fluctuating flows during minimum release years. Combined with flood control, this would result in dryer conditions for vegetation in the NHWZ. Young tamarisk would be concentrated near the 16,300-cfs stage, while mesquite and other native species would dominate the NHWZ.

Emergent marsh plants would continue to occupy postdam sites plus expand into suitable sites created by lower maximum flows. Patches above the stages equivalent to 16,300 cfs would no longer be subject to frequent inundation. These sites would be dry, and the marsh plants eventually would be replaced by woody plants (see VEGETATION in this chapter). A reduction in maximum stage would create or make available additional sites suitable for marsh plants. However, the aggregate area of marsh plants supported under this alternative would be less than under no action.

Minimum flows of 8,000 cfs year-round would benefit the **aquatic food base** and, therefore, wintering waterfowl. This increase represents about a 3.4- (Lees Ferry) to 5.3-foot (near the dam) increase in stage and up to a 20.5-foot increase in wetted perimeter.

Seasonally Adjusted Steady Flow Alternative

Habitat maintenance flows under this alternative would have effects on riparian habitat similar to those discussed under the Moderate Fluctuating Flow Alternative. The area available for expansion of **woody plants** would be between the maximum area of stabilized sandbars without maintenance flows—26 to 36 feet (38 to 58 percent) over no action—and the area unaffected by maintenance flows—0 to 5 feet (0 to 12 percent) over no action (see VEGETATION in this chapter). The increase in woody plants, and therefore wildlife habitat, would approach the potential maximum area of stabilized sandbars under this alternative.

Under this alternative, some patches of **emergent marsh plants** and the wildlife that use these sites as habitat would: (1) completely lose their water supply for 5 months, (2) be partially inundated for 5 months, or (3) be completely inundated for 2 months (plus a 1- to 2-week period during maintenance flows). The reduced maximum stage would create or make available additional sites suitable for marsh plant development. Overall, however, fewer marsh plants would be supported under this alternative than under no action (see VEGETATION in this chapter).

Increased minimum flows would benefit the aquatic food base and, therefore, wintering waterfowl. This increase represents a stage increase of 3.4- (Lees Ferry) to 5.3-feet (near the dam) and up to a 20.5-foot increase in wetted perimeter.

Year-Round Steady Flow Alternative

Area of riparian habitat, represented by **woody plants** in the NHWZ, would expand down to the 11,400-cfs stage during minimum release periods under this alternative. The area of beach available for expansion of woody riparian plants would average 36 to 57 feet, or a 63- to 94-percent increase over no action conditions.

A zone between about 11,400 and 31,500 cfs would no longer be inundated by fluctuating flows during minimum release years. Combined with flood control, this would result in dryer conditions for NHWZ vegetation. Young tamarisk would be concentrated near the 11,400-cfs stage, while mesquite and other native species would dominate the NHWZ.

Emergent marsh plants would occupy suitable sites created by lower maximum flows. Patches above the 11,400-cfs stage no longer subject to frequent inundation would be replaced by woody plants. The aggregate area of emergent marsh plants supported by this alternative would be less than that under no action.

Increased minimum flows year-round would benefit the **aquatic food base** and, therefore, wintering waterfowl. Increased minimum flows represent an additional 10,400 cfs of permanent inundation over no action conditions. This increase represents a stage increase of about 4.3 (Lees Ferry) to 6.9 feet (near the dam) and up to a 25.9-foot increase in wetted perimeter.

ENDANGERED AND OTHER SPECIAL STATUS SPECIES

Issue:

How do dam operations affect the populations of ENDANGERED AND OTHER SPECIAL STATUS SPECIES throughout Glen and Grand Canyons?

Indicators:

Reproduction, recruitment, and growth of **humpback chub**, **razorback sucker**, and flannelmouth sucker
Trout and aquatic food base for **bald eagle**
Aquatic food base for **belted kingfisher**
Area of woody plants for **southwestern willow flycatcher**
Maximum flow for **Kanab ambersnail**

Both aquatic and terrestrial special status species occupy or use the river corridor through Glen and Grand Canyons. Because the river is regulated by Glen Canyon Dam, special status native fish could be directly affected by changes in dam operations.

For example, minimum flows below some stage may limit access to tributaries. In contrast, the effects on terrestrial species would be more indirect and occur through dam-induced changes in habitat. For example, an uncontrolled flood event could eliminate nesting habitat for the southwestern willow flycatcher and thus reduce the numbers of young flycatchers produced in Grand Canyon.

In an attempt to reduce repetition of information, impacts on special status native fish are not presented in this section. Readers interested in a detailed assessment of impacts on humpback chub and razorback and flannelmouth suckers should refer to the FISH section of this chapter.

Analyses of the indicators for terrestrial special status species are limited to the river corridor between Glen Canyon Dam and Separation Canyon (although data only to Diamond Creek are available). The analyses rely heavily on work presented in other sections. For example, the analysis presented in the FISH section of this chapter provides information for impact assessment relevant to the bald eagle and belted kingfisher. Evaluation of habitat for the southwestern willow flycatcher is based on analyses presented in chapter IV, VEGETATION.

Three special status species discussed in chapter III would not be affected by changes in dam operations. These species—southwestern river otter, peregrine falcon, and osprey—are discussed below and are not treated under the individual alternatives. A fourth species, the **Kanab ambersnail**, would be affected by maximum flows above 20,000 cfs. Effects would be similar among alternatives and are discussed in the "Summary of Impacts" and not under the individual alternatives.

The **southwestern river otter** is a subspecies considered extinct and will not be treated further. Any river otter in Arizona is regarded as an escaped individual from a reintroduced population of unknown subspecies.

Numbers of **peregrine falcons** are increasing nationwide following the prohibition on use of certain pesticides in the 1970's. It is assumed that increases in peregrine numbers have occurred in Grand Canyon as well (Brown et al., 1992). Although the reasons for these apparent increases are undoubtedly complex, changes in primary productivity within the river following construction of Glen Canyon Dam and subsequent increases in the peregrine falcon's prey base (swallows, swifts, and bats) are assumed to have played a major role (Carothers and Brown, 1991).

Primary productivity within the river is controlled by many factors, but the alternatives would affect only light transmittance through changes in water clarity. Sediment mixing from fluctuating releases and sediment supply from tributaries both affect river water clarity. The alternatives may affect sediment mixing through changes in daily fluctuation patterns. If such effects occur, they would be difficult to quantify but would be assumed to improve water clarity somewhat over no action conditions (except for the Maximum Powerplant Capacity Alternative). Improved water clarity would result in improved food conditions for peregrine falcons via food-chain linkages described in chapter III.

No data exist to indicate that peregrine falcons within Grand Canyon are limited by lack of food. In fact, recent surveys indicate that available nesting habitat may be approaching full occupancy (Brown et al., 1992). The availability of suitable nesting territories would then limit future populations. In summary, the alternatives would not affect nest sites within nesting territories and may improve food base conditions. Therefore, it is concluded that none of the alternatives would affect peregrine falcons in Grand Canyon.

Ospreys seen along the river in Grand Canyon are assumed to be transients using the river as a travel lane to other habitat. None of the alternatives would affect the river's suitability as a travel lane and, therefore, ospreys are not treated further in this report.

FWS issued a final biological opinion on the preferred alternative containing a finding of no jeopardy for the bald eagle, Kanab ambersnail, and peregrine falcon and a jeopardy finding for the humpback chub and razorback sucker. In accordance with the regulations governing proposed species and proposed critical habitat, Reclamation is currently conferencing with FWS on the status of the southwestern willow flycatcher (see chapter V). Components of the final reasonable and prudent alternative (attachment 4), which could in the future remove the likelihood of jeopardizing the continued existence of the humpback chub and razorback sucker, have been incorporated into the preferred alternative.

Analysis Methods

Special status species occupy diverse niches in the Grand Canyon ecosystem. Unlike the topic of "wildlife," no single resource can be used as an indicator of impacts to special status species. Studies of rare species might describe parameters characteristic of remaining habitats that reflect marginal rather than optimal conditions. Management recommendations based on limited data for special status species risk perpetuating marginal conditions. The analyses approach taken here relies on the concept of linkages among resources.

Daily dam operations would affect some special status species directly and others indirectly during the short term. Because population data are limited for most special status species, the indicators presented at the beginning of this section will be used to evaluate effects of the alternatives on the species of concern.

Because bald eagles use trout as food when available, it is assumed that impacts discussed under the short-term period of analysis (i.e., daily operations) would be identical to long-term impacts. This assumption is supported by the observation that uncontrolled flood releases historically have occurred in the spring or early summer after the period of eagle use. In addition, it is assumed that a trout fishery would be maintained in the future, and trout would continue to attempt tributary spawning if conditions permit.

Although there is no evidence that the southwestern willow flycatcher is habitat-limited in Grand Canyon, uncontrolled flood events would reduce area coverage of riparian vegetation and would probably affect habitat patch size. The relationships among habitat requirements, patch size, and willow flycatchers in Grand Canyon are not understood. However, a reduction in area of riparian vegetation below some threshold likely would affect habitat suitability for this species. Because the level of this threshold is unknown, reductions in riparian vegetation should be avoided. Such avoidance is best accomplished through flood control.

Effects on the belted kingfisher would follow effects on fish—basically the relationship between daily operations, tributary access, and the aquatic food base. Flood frequency reduction measures and beach/habitat-building flows should benefit native fish in the long term over no action conditions. Belted kingfishers would benefit from any improvement in habitat conditions for fish.

Summary of Impacts: Endangered and Other Special Status Species

Table IV-12 summarizes impacts on endangered and other special status species. The endangered and special status fish species are influenced by factors and processes similar to those described for native fish species and are discussed in this chapter under FISH.

Many of the action alternatives would affect minimum flows and therefore affect tributary access and the aquatic food base used as indicators in impact assessment for both bald eagles and belted kingfishers. The No Action and Maximum Powerplant Capacity Alternatives have a minimum discharge of 1,000 cfs. The remaining alternatives increase minimums from 3,000 cfs up to 11,400 cfs under the Year-Round Steady Flow

Table IV-12. Summary[1] of anticipated impacts on ENDANGERED AND OTHER SPECIAL STATUS SPECIES during the short-term period of analysis by alternative

ENDANGERED AND OTHER SPECIAL STATUS SPECIES	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Endangered species									
Humpback chub[2]	Stable to declining	Same as no action	Same as no action	Same as no action	Potential minor increase	Potential minor increase	Uncertain potential minor increase	Uncertain potential major increase	Uncertain potential minor increase
Razorback sucker	Stable to declining	Same as no action	Same as no action	Same as no action	Potential minor increase	Potential minor increase	Uncertain potential minor increase	Uncertain potential minor increase	Uncertain potential minor increase
Bald eagle	Stable	Same as no action	Same as no action	Potential increase	Potential increase	Potential increase	Potential increase	Potential increase	Potential increase
Peregrine falcon	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect
Kanab ambersnail[3]	No effect	Some incidental take	Some incidental take	Some incidental take	Some incidental take	Some incidental take	Some incidental take	Some incidental take	Some incidental take
Candidate species									
Flannelmouth sucker	Stable to declining	Same as no action	Same as no action	Same as no action	Potential minor increase	Potential minor increase	Uncertain potential minor increase	Uncertain potential major increase	Uncertain potential minor increase
Southwestern willow flycatcher	Undetermined increase	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action
Arizona species of concern									
Southwestern river otter	Presumed extinct	Presumed extinct	Presumed extinct	Presumed extinct	Presumed extinct	Presumed extinct	Presumed extinct	Presumed extinct	Presumed extinct
Belted kingfisher	Stable	Same as no action	Same as no action	Potential increase	Potential increase	Potential increase	Potential increase	Potential increase	Potential increase
Osprey	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect	No effect

[1] As discussed in the text, these summaries are based on analyses presented in this chapter under FISH and VEGETATION.
[2] Analysis of impacts on humpback chub, razorback sucker, and flannelmouth sucker can be found in this chapter under FISH.
[3] Incidental take occurs when some mortality results from authorized operations. Consultation between Reclamation and FWS are ongoing to determine an acceptable level of incidental take.

Alternative. Increased minimum flows are assumed to benefit tributary access and the aquatic food base.

Although not treated in detail in this section, it should be noted that native fish reproduction in the mainstem is restricted by cold temperature (see FISH in this chapter). Native fish are a food source for other special status species. Limited spawning in the mainstem near warm springs and tributary confluences may occur when fluctuations are reduced. Some mainstem spawning of humpback chub occurred in 1993, but no recruitment was recorded (Arizona Game and Fish Department, 1994). The significance of such mainstem spawning to special status species is unknown.

The Grand Canyon population of Kanab ambersnails generally occurs above the elevation equivalent to a river stage of 40,000 cfs, although the population size appears to vary widely between seasons. Prior to interim flows, Kanab ambersnails were found above the no action maximum flow level of 31,500 cfs. Since interim flows were implemented, individual ambersnails have been found near the river's edge at 20,000 cfs. A survey and habitat evaluation conducted in September 1994 indicated that a large number of Kanab ambersnails were present between the 20,000- and 45,000-cfs flow levels. When compared to no action conditions (prior to interim flows), none of the alternatives would affect ambersnails. However, these survey results make an analysis using this baseline invalid. Therefore, current data were incorporated into the analysis.

Reclamation's GCES and FWS are closely monitoring the Grand Canyon Kanab ambersnail population. Although studies are underway, the area of habitat occupied by Kanab ambersnails is unknown, and any evaluation of the importance of maximum flows on habitat area is difficult to determine. FWS estimates that approximately 2 square yards of habitat are affected at flows of 20,000 cfs. As flows increase, more area is affected: 5 square yards at 25,000 cfs, 50 square yards at 33,000 cfs, and 103 square yards at 45,000 cfs.

All alternatives would potentially affect Kanab ambersnail habitat or individuals because all alternatives either have maximum flows above 20,000 cfs or contain provisions for beach/habitat-building and habitat maintenance flows that would be above 20,000 cfs. Since this population survived the 1983-86 floodflows (90,000 cfs), it is assumed that infrequent flows of about 45,000 cfs would not jeopardize the continued existence of the Kanab ambersnail population in Grand Canyon.

Some incidental take of Kanab ambersnails would likely occur under all alternatives. Incidental take is unavoidable mortality resulting from authorized activities such as dam operations. Some mortality would likely occur upon implementation of the selected alternative and again during either habitat maintenance or beach/habitat-building flows. Consultation under the Endangered Species Act would be necessary to determine reasonable and prudent measures necessary or appropriate to minimize such impacts. Consultation between Reclamation and FWS is ongoing.

The area of woody riparian vegetation is used as an indicator of potential habitat for the southwestern willow flycatcher, although changes in potential habitat may not translate into changes in bird numbers. The Maximum Powerplant Capacity Alternative would result in less riparian vegetation, the No Action Alternative would show no change, and the remaining alternatives would all support varying degrees of increase in woody plants. Periodic beach/habitat-building flows would maintain these conditions (see VEGETATION in this chapter).

Some alternatives include habitat maintenance flows designed to re-form beaches and backwaters. Habitat maintenance flows would provide high (up to 33,200 cfs), steady flows for 1 to 2 weeks each spring when Lake Powell is near or below 19 maf.

For terrestrial special status species, maintenance flows would:

- Support a general increase in woody plants
- Have no effect (because of short duration) on the aquatic food base

Unrestricted Fluctuating Flows

No Action Alternative

Analyses of effects on special status species under no action conditions in the short term basically project existing trends. It should be noted that habitat use by two of the three special status birds (bald eagles and willow flycatchers) has developed postdam under conditions similar to no action.

Humpback Chub and Razorback and Flannelmouth Suckers. The analysis of impacts on special status native fish is presented in the FISH section of this chapter. In general, populations of native fish are considered stable to declining under no action conditions.

Bald Eagle. Bald eagle use of Grand Canyon primarily is linked to the presence of trout in the Colorado River—specifically, the abundance of trout attempting to spawn in Nankoweap Creek. It is possible that numbers of eagles will continue to increase—if trout remain abundant—and eventually disperse to other locations within the study area. However, the focus of this analysis is tributary access for spawning trout. It is assumed that low flows of 1,000 cfs under no action conditions would limit trout access to tributary spawning sites during some periods.

The aquatic food base is certainly important to many resources including special status native fish (see FISH in this chapter). However, changes in wetted perimeter are used here to estimate effects on trout, which are prey for bald eagles. Baseline conditions for wetted perimeter under 1,000-cfs minimum flows are 580.3 feet near the dam and 380.4 feet near Lees Ferry.

Belted Kingfisher. Belted kingfishers use the river and its tributaries for feeding and nest in suitable banks wherever they are found. Nesting banks would not be affected under any alternative, but low minimum flows would periodically restrict tributary access for fish and limit the aquatic food base potential.

Food production and availability would be both benefited and disadvantaged by fluctuating flows. Fluctuations may displace *Cladophora* and associated diatoms and invertebrates and provide them as drift downstream of Glen and Marble Canyons. Excessive disturbance would reduce productivity of food resources, extended periods of extreme low flows would desiccate algae, and high flows would inundate some algae beyond the depth of usable light for photosynthesis (Angradi et al., 1992).

Southwestern Willow Flycatcher. Data are not available that can be used to interpret specific relationships between breeding willow flycatchers and woody plants used as nesting habitat in Grand Canyon. However, the analysis presented here assumes that conditions that would change the area of woody plants would result in changes in area of potential habitat for willow flycatchers. No data were discovered that indicate that numbers of willow flycatchers using Grand Canyon are habitat-limited.

The composition of woody plants within the riparian corridor (exclusive of the OHWZ) would follow trends described in chapter III, with coyote willow, arrowweed, honey mesquite, and other species increasing in abundance. Southwestern willow flycatchers in Grand Canyon nest in large patches of riparian vegetation. Conditions that favor increases in woody plants are assumed to favor potential habitat for this species.

Maximum Powerplant Capacity Alternative

Analysis of impacts on **humpback chub** and **razorback** and **flannelmouth suckers** are presented in the FISH section of this chapter. Populations of native fish under this alternative are considered the same as under no action conditions.

Tributary access for trout used as prey by bald eagles would not change from no action conditions.

Because minimum flows would not differ from no action under this alternative, no change would occur in the area of wetted perimeter. Therefore, conditions for the aquatic food base—important in supporting trout and other fish used as prey by bald eagles and belted kingfishers—would not change.

An increase in maximum stage under this alternative would affect woody plants and, therefore, may affect potential habitat of the southwestern willow flycatcher. Under this alternative, unstable sandbar width would increase by 0 to 9 percent (0 to 5 feet) over no action. Vegetation occupying unstable sites would be lost through erosion.

In summary, tributary access and wetted perimeter would not change. Thus, conditions for bald eagles and belted kingfishers would not change under this alternative. However, woody plants that may be potential habitat for **southwestern willow flycatchers** would be reduced. Therefore, conditions for the willow flycatcher under this alternative would be less favorable than those under no action.

Restricted Fluctuating Flows

Factors such as minimum discharge, which would affect numbers or availability of trout in Nankoweap Creek and to a lesser degree in the river corridor, would likely affect bald eagles. None of the alternatives would affect parameters of Nankoweap Creek—such as discharge, water temperature, or icing—that are important in determining the creek's suitability as a trout spawning site.

Trout stranded in isolated pools would be available as food for bald eagles. Location of foraging efforts are affected by fluctuating flows; however, these patterns do not appear to affect foraging success. This impact analysis is based solely on trout access to tributaries (Nankoweap Creek) and effects on the aquatic food base. All restricted fluctuating flow alternatives have minimum flows higher than no action conditions, but only the Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives have minimum flow restrictions of 5,000 cfs or greater that would permit unlimited tributary access. Minimum discharge is an important parameter in defining the aquatic food base and, thus, food for fish and belted kingfishers.

The effects of alternative operations on habitat for the southwestern willow flycatcher are presented in terms of anticipated flows during a minimum release year. In moderate or high water years, riparian vegetation under the High, Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives would be affected by higher water volumes through increases in maximum stages. During moderate or high water years, total area coverage of riparian vegetation may be reduced.

High Fluctuating Flow Alternative

Analysis of impacts on humpback chub and **razorback** and **flannelmouth sucker** is found in this chapter under FISH. Populations of native fish under this alternative are considered the same as no action (stable to declining).

Increased minimum flows to 3,000 cfs year-round would mean some increase in tributary access and some benefits to *Cladophora* and the aquatic food base. These are assumed to benefit **bald eagles** and **belted kingfishers** through their linkages to trout and the aquatic food base. Increased low flows represent an additional 2,000 cfs of permanent inundation—a 1.5- (at Lees Ferry) to 2.0-foot (near the dam) increase in stage and up to an 8.7-foot increase in wetted perimeter over no action.

Under this alternative, riparian vegetation would increase 10 to 15 feet (15 to 35 percent) over no action conditions (see VEGETATION in this chapter). Thus, some change in potential habitat for the **southwestern willow flycatcher** would occur. However, it should be noted that increases in potential habitat may not translate into increases in the numbers of flycatchers surveyed during any future monitoring program.

Moderate Fluctuating Flow Alternative

Analysis of impacts on **humpback chub** and **razorback** and **flannelmouth sucker** is found in this chapter under FISH. Populations of native fish under this alternative are considered the same as no action (stable to declining).

Increased minimum flows of 5,000 cfs year-round would mean some increase in tributary access and some benefits to *Cladophora* and the aquatic food base. These conditions also would be assumed to benefit **bald eagles** and **belted kingfishers** through their linkages to trout and the aquatic food base. Increased low flows represent an additional 4,000 cfs of permanent inundation—a 2.4- (at Lees Ferry) to 3.5-foot (near the dam) increase in stage and up to a 14.1-foot increase in wetted perimeter over no action.

Riparian vegetation would increase over no action conditions. The area of beach available for expansion of woody plants would average 0 to 6 feet, or an increase of 0 to 40 percent over no action (see VEGETATION in this chapter). This change is assumed to indicate an increase in potential habitat for the **southwestern willow flycatcher**.

For terrestrial special status species, maintenance flows would provide unlimited access to tributaries important to spawning trout (and therefore bald eagles), support a general increase in woody plants that may be used as habitat (southwestern willow flycatcher), and have no effect on the aquatic food base (an important consideration for eagles and belted kingfishers).

In summary, both tributary access—important for trout reproduction—and the aquatic food base—important to bald eagles and belted kingfishers—would increase under this alternative. Thus, food conditions for bald eagles and belted kingfishers would be enhanced, and woody plants that may be potential habitat for southwestern willow flycatchers would increase.

Modified Low Fluctuating Flow Alternative

The FWS biological opinion on this preferred alternative stated that the Modified Low Fluctuating Flow Alternative would likely not jeopardize the continued existence of the bald eagle, peregrine falcon, and Kanab ambersnail but would likely jeopardize the humpback chub and razorback sucker. Therefore, the preferred alternative was designed to be consistent with the "reasonable and prudent alternative" (see attachment 4) contained in the biological opinion. The reasonable and prudent alternative was provided as a plan that could remove the likelihood of jeopardizing the continued existence of the humpback chub and razorback sucker in Grand Canyon (see FISH in this chapter).

Analysis of impacts on **humpback chub** and **razorback** and **flannelmouth suckers** can be found in this chapter under FISH. Under this alternative, populations of native fish are expected to have the potential for minor increases.

The aquatic food base is important in supporting trout and other fish used as prey by **bald eagles** and **belted kingfishers**. Wetted perimeter would increase over no action 14.1 feet near the dam and 14.1 feet near Lees Ferry under this alternative. It is assumed that because both reliable minimum flows and wetted perimeter increase, conditions for the aquatic food base would also improve.

A decrease in maximum stage would affect woody plants and, therefore, may affect potential habitat of the **southwestern willow flycatcher**. Because this alternative includes habitat maintenance flows, the exact change in area of woody plants is difficult to predict. However, the area available for woody plant expansion would be between the potential maximum area of stabilized sandbars—21 to 31 feet (30- to 47-percent increase over no action) and the area unaffected by maintenance flows—0 to 5 feet (0- to 12-percent increase). It is assumed that an increase in woody plants would indicate an increase in potential habitat for the willow flycatcher.

As described under the Moderate Fluctuating Flow Alternative, habitat maintenance flows are expected to re-form and prepare backwaters for later use by larval and young-of-year fish.

Terrestrial species would experience the same effects (or lack of effects) discussed under the Moderate Fluctuating Flow Alternative.

In summary, both tributary access and the aquatic food base would increase under this alternative. Thus, conditions for bald eagles and belted kingfishers would be enhanced. Woody plants that may be potential habitat for southwestern willow flycatchers would increase. Therefore, for all special status species, habitat conditions would increase over no action.

Interim Low Fluctuating Flow Alternative

Analysis of impacts on **humpback chub** and **razorback** and **flannelmouth suckers** is presented in this chapter under FISH. Under this alternative, populations of native fish are expected to have the potential for minor increases.

Wetted perimeter would increase over no action 14.1 feet near the dam and 14.1 feet near Lees Ferry under this alternative. It is assumed that because both reliable minimum flows and wetted perimeter increase, conditions for the aquatic food base would improve. The aquatic food base is important in supporting trout and other fish used as prey by bald eagles and belted kingfishers.

A decrease in maximum stage under this alternative would affect woody plants and, therefore, may affect potential habitat for the southwestern willow flycatcher. The area available for woody plant expansion would average 21 to 31 feet (30- to 47-percent increase over no action). It is assumed that an increase in woody plants indicates an increase in potential habitat for the willow flycatcher.

In summary, under the Interim Low Fluctuating Flow Alternative:

Aquatic food base, important to bald eagles and belted kingfishers, would increase.

- Woody plants that may be potential habitat for willow flycatchers would increase.

Therefore, habitat conditions would increase for all special status species over no action.

Steady Flows

General effects of steady flow patterns on tributary access and the aquatic food base were described under FISH, and effects on woody plants were described under VEGETATION.

Existing Monthly Volume Steady Flow Alternative

Analysis of impacts on humpback chub and **razorback** and **flannelmouth suckers** can be found in this chapter under FISH. Under this alternative, populations of native fish have the potential to experience a major increase.

Increased minimum flows of 8,000 cfs year-round would mean increased tributary access and large benefits to *Cladophora* and the aquatic food base. These would be assumed benefits to **bald eagles** and **belted kingfishers** through linkages to trout and the aquatic food base. Increased minimum flows represent an additional 7,000 cfs of permanent inundation—a 3.4- (at Lees Ferry) to 5.3-foot (near the dam) increase in stage and up to a 20.5-foot increase in wetted perimeter over no action.

Riparian vegetation would increase over no action conditions under this alternative. The area of beach available for expansion of woody plants would average 26 to 41 feet, or an increase of 45 to 65 percent over no action. This change is assumed to indicate an increase in potential habitat for the **southwestern willow flycatcher**.

Seasonally Adjusted Steady Flow Alternative

Analysis of impacts on **humpback chub** and **razorback** and **flannelmouth suckers** can be found in this chapter under FISH. Under this alternative, populations of native fish have the potential to experience a major increase.

Minimum flows of up to 8,000 cfs year-round would mean increased tributary access and large benefits to *Cladophora* and the aquatic food base. These would be assumed benefits to **bald eagles** and **belted kingfishers** through linkages to trout and the aquatic food base. Increased low flows represent an additional 7,000 cfs of permanent inundation—a 3.4- (at Lees Ferry) to 5.3-foot (near the dam) increase in stage and up to a 20.5-foot increase in wetted perimeter over no action.

Riparian vegetation would increase over no action conditions under this alternative. The area of beach available for expansion of woody plants would range from 0 to 36 feet, or an increase of 0 to 58 percent over no action (see VEGETATION in this chapter). This change is assumed to indicate an increase in potential habitat for the **southwestern willow flycatcher**.

In summary, under the Seasonally Adjusted Steady Flow Alternative:

- Aquatic food base, important to bald eagles and belted kingfishers, would increase.
- Woody plants that may be potential habitat for willow flycatchers would increase.

Therefore, habitat conditions would increase for special status species over no action. Because this alternative would provide flow conditions closer to predam conditions than any other alternative, it is believed to be the most beneficial alternative for native fish.

Year-Round Steady Flow Alternative

Analysis of impacts on **humpback chub** and **razorback** and **flannelmouth suckers** can be found in this chapter under FISH. Under this alternative, populations of native fish have the potential to experience a major increase.

Minimum flows of 11,400 cfs year-round would mean increased tributary access and large benefits to *Cladophora* and the aquatic food base. These also would be assumed benefits to **bald eagles** and **belted kingfishers**. Increased low flows represent an additional 10,400 cfs of permanent inundation—a 4.3- (at Lees Ferry) to 6.9-foot (near the dam) increase in stage and up to a 25.9-foot increase in wetted perimeter over no action.

Riparian vegetation would increase over no action conditions under this alternative. The area of beach available for expansion of woody plants would average 36 to 57 feet, or an increase of 63 to 94 percent over no action. This change would indicate an increase in potential habitat for the **southwestern willow flycatcher**.

CULTURAL RESOURCES

Issue:

How do dam operations affect the continued existence of CULTURAL RESOURCES in Glen and Grand Canyons?

Indicators:

Number of **archeological sites** directly, indirectly, or potentially affected
Number of **Native American traditional cultural properties and resources** directly, indirectly, or potentially affected

Cultural resources in the Colorado River corridor are numerous, with 475 archeological sites and 489 isolated occurrences documented between Glen Canyon Dam and Separation Canyon. Isolated occurrences are findings of artifacts or other remains located apart from an archeological site. Because it can be inaccurate to determine the *National Register of Historic Places* (National Register) eligibility of a single artifact, isolated occurrences were not used in the impact analysis.

In addition to those resources identified as archeological sites, numerous additional resources significant to Native Americans occur within the river corridor. These resources, which are culturally important because they represent areas of spiritual significance and/or traditional use, are called traditional cultural properties and resources in this document. Though there is some overlap between categories, traditional cultural properties and traditional cultural resources are discussed separately from properties identified as archeological sites.

Of the archeological sites located during the survey, 336 either have been affected by the existence and operation of Glen Canyon Dam or have the potential to be affected by floodflows that could be released from the dam. The remaining 139 sites are unaffected by the dam and have been excluded from further discussion. The specific sites identified as potentially impacted are all locations which contain physical manifestations and are recorded as archeological sites. Some archeological sites are also important as traditional cultural properties. Impacts to archeological sites, including those with traditional cultural significance, are discussed for each alternative.

Determination of eligibility for the National Register was concurred by the Arizona State Historic Preservation Officer for the 336 sites potentially impacted by dam operations (attachment 5). Of these identified sites, 319 have been determined eligible for inclusion on the register, 16 are ineligible, and 1 will require testing.

Criteria for National Register eligibility include those used for evaluating the significance of archeological properties under 36 CFR 60.4 and the guidelines for evaluating traditional cultural properties (Parker and King, no date). Specific details on individual site impacts are found in a technical archeological survey report (Fairley et al., 1994).

Numerous locations within the project area contain no archeological remains but are nonetheless tangible sites and places with cultural significance because of their use in Native American practices and beliefs. Virtually all prehistoric sites are affiliated with contemporary Indian Tribes, often more than one group due to multiple traditions or multiple uses of many sites found along the Colorado River. These traditional cultural properties are considered eligible for the National Register if they are rooted in the living community's history and important in maintaining the community's cultural identity.

Traditional cultural properties can include specific plant gathering areas, landforms, springs, prayer offering locations (shrines), archeological sites, ancestral burials, mineral deposits, and other resource collection sites.

In addition, many resources are extremely important, or even vital, for continuing traditional cultural practices, but may be obtained in many locations. These traditional resources, because they are not place-specific or because they encompass large areas as cultural landscapes, are not eligible for the National Register. Their importance to Native Americans, however, is not lessened because of the way current cultural preservation law is defined. In addition, many of them are governed by the National Park Service (NPS) management policies that require all cultural landscapes to be treated as cultural resources, regardless of the type or level of significance.

Summary of Impacts: Cultural Resources

Impact analyses of cultural resources under alternative dam operations are based on the present understanding of changes in these resources known to have occurred as a result of Glen Canyon Dam. Some impacts are direct, while others are indirect. Predicted influences of alternatives on traditional cultural properties and resources are based on information provided by ethnographic research and knowledge shared by Indian Tribes known to have contemporary and ancestral involvement with Grand Canyon.

Evaluation of isolated occurrences along the river corridor is ongoing by individual tribes and, if they are determined to be traditional cultural properties, their potential for impacts will be assessed. Anticipated impacts to certain other cultural resources are linked to impacts on riparian vegetation. A summary of impacts on cultural resources resulting from all alternatives is shown in table IV-13. Impacts on cultural resources are irretrievable and generally regional or national in scope.

Table IV-13.—Summary of anticipated impacts on CULTURAL RESOURCES by alternative

CULTURAL RESOURCES	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Archeological sites	Major (336)	Major (336)	Potential to become major (263)	Moderate (less than 157)	Moderate (less than 157)	Moderate (less than 157)	Moderate (less than 157)	Moderate (less than 157)	Moderate (less than 157)
Traditional cultural properties	Major	Same as no action	Potential to become major	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Traditional cultural resources	Major	Same as no action	Same as no action	Increased protection	Increased protection	Increased protection	Increased protection	Increased protection	Increased protection

Note: Number of sites potentially impacted are in parentheses.

Moderate: Readily apparent impacts attributable to current operations; determination of "no adverse effect" or "adverse effect" within 36 CFR Part 800 likely.

Potential to become major: Potentially severe adverse impact from direct or indirect effects related to operations; determination of "no adverse effect" or "adverse effect" within 36 CFR Part 800 likely.

Major: Severe adverse impacts from direct or indirect effects related to operations as defined by 36CFR Part 800; determination of "adverse effect" with likely mitigation involving complete data recovery.

With the closure of Glen Canyon Dam in 1963, the pattern of deposition, erosion, and flooding on the Colorado River through Glen and Grand Canyons was changed forever. As a result, general loss of river-deposited terraces has occurred. Archeological sites and traditional cultural properties once protected by sandbars and terraces have become increasingly exposed to erosion by the river and rainfall-induced terrace erosion (see figure III-22).

The postdam river cannot rebuild high terraces, resulting in more site erosion than occurred during the predam environment (see discussion of high terraces in chapter III, SEDIMENT). The 1983-86 floodflows were known to cause direct erosion of terraces. Extreme rainfall conditions during 1978-85 led to accelerated erosion of archeological sites and traditional cultural properties. Because the dam traps sediment and reduces floods, little or no sediment is deposited at the mouths of small ephemeral tributary streams, which makes the situation worse. Only low elevation sediment deposits can be replenished in the postdam environment. Large sediment-laden floods may rebuild the bases of high terraces at most locations but erode terraces at other locations.

The initial impacts to archeological sites and traditional cultural properties began with the construction of Glen Canyon Dam and the resulting change in the amount and distribution of sediment. These sites depend on the terraces that have formed along the river corridor. Without a mechanism for sediment augmentation and redeposition to predam terrace levels, all alternative operations would impact cultural resources. None of the action alternatives considered in this EIS could alter the basic change in postdam sediment input to the system; thus, it is expected that dam-related impacts to archeological sites would continue regardless of alternative flow patterns. These impacts are permanent; the damage irretrievable. However, the rate at which impacts would occur could be affected by alternative operations, principally through flood frequency reduction measures.

Many of the traditional cultural resources (especially riparian plant and animal species) also depend on sandbars and terraces along the river. The alternatives that allow for maximum growth and protection of the riparian habitat also would favor protection of these traditional resources.

Postdam changes in the riparian ecosystem within Grand Canyon have favored growth of NHWZ vegetation, while OHWZ vegetation is thought to be declining (chapter III, VEGETATION). The net effect of these changes in riparian vegetation is still in a dynamic state; however, some of the traditional resources (willows, giant reeds, yellow warblers, yellow-throats, and other plants and riparian birds) have clearly increased since construction of the dam. Although none of the action alternatives would influence OHWZ vegetation, the extent of the NHWZ—and thus the abundance of some traditional resources—would be affected by alternative discharge patterns.

It is important to note that the alternatives that restrict maximum flows to less than powerplant capacity (33,200 cfs) would allow an increase in NHWZ vegetation during low water years. During moderate and high water years, water releases could increase to a maximum of 33,200 cfs, thus limiting the area of sediment deposits available for vegetation growth.

One well-known traditional cultural property located within the river corridor, the salt mines and associated sediment deposits, would be better protected by alternatives that allow sediment accumulation on the sandbar at the base of the mines.

Generally, alternatives that have the capability to maintain the sediment balance and allow for sediment distribution along the river corridor would enhance long-term preservation of cultural resources. Although sediment transport is variable and depends on flow regimen, alternatives that would most likely produce a net positive sand balance in the system—while maintaining a high base level of sediment deposition—would be most favorable. The alternatives listed below would allow for a net positive sediment balance in the system and the possibility of sediment redeposition in areas that would protect cultural resources:

- Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives
- All steady flow alternatives

Sediment deposition is a critical factor in preserving terraces and related deposits that contain cultural resources. This is particularly true in the areas between Glen Canyon Dam and the LCR, where predam terraces are often in direct contact with the river. Although impacts to some sites would still occur due to the existence of the dam, it is likely that the rate of impact would be less than under no action.

Of the elements common to all restricted fluctuating flow and steady flow alternatives, the most important for cultural resource protection is flood frequency reduction. The flood releases during 1983-86 caused direct erosion of approximately 33 archeological sites and scoured or buried a large portion of the riparian vegetation in the NHWZ. Another uncontrolled flood of that magnitude and duration (4 plus years) could severely damage or destroy certain archeological sites—principally in Glen and Marble Canyons— and temporarily destroy riparian vegetation. Adopting flood frequency reduction measures would reduce the risk of uncontrolled flooding, thereby helping to preserve the river's physical cultural history.

Reduced flood frequency is included in all of the alternatives except no action and maximum powerplant capacity. It is assumed that with flood control, flows greater than 45,000 cfs would not occur more often than once in 100 years on average, except for beach/habitat-building flows.

The habitat maintenance and beach/habitat-building flows described in chapter II might benefit some of the cultural resources in the system. Adding sediment at the mouths of tributaries and creating sandbars at slightly higher elevations is a systemwide approach to rebuilding and slowing the erosion of the high terraces upon which the sites depend. Although more research is needed on the success of these flows, creation of stable sandbars—even at lower levels—could result in a more stable situation for predam terraces.

The concept of adaptive management has implications for cultural resources. National Historic Preservation Act requirements recommend a long-term monitoring program (through a programmatic agreement and historic preservation plan) to assess changing conditions of cultural resources. Long-term monitoring is now required under the Grand Canyon Protection Act of 1992. These assessments of site integrity and stability offer mechanisms for remedial actions which include site-specific mitigation along with management alternatives which could affect the entire system. The actions described in the programmatic agreement and accompanying monitoring plans are common to all alternatives (attachment 5).

Unrestricted Fluctuating Flows

No Action Alternative

Archeological Sites. Under no action conditions, continued degradation and eventual loss of significant prehistoric and historic archeological sites would occur. It should be noted that all archeological resources are nonrenewable, and damage to them is both irretrievable and irreversible. Impacts to these sites are categorized as follows:

- Direct impacts = 33 sites
- Indirect impacts = 124 sites
- Potential impacts = 179 sites

The potential for degradation of all 336 archeological sites would continue due to the loss of sediment in the system, arroyo-cutting through predam river-deposited terraces, and the risk of uncontrolled flooding. Sediment erosion and arroyo-cutting are linked to archeological site erosion. Impacts from the dam and its operations have occurred since 1963, with direct and indirect damage documented for 157 sites. Continuation of dam operations under the No Action Alternative could lead to the eventual loss of all 336 sites identified within the river corridor.

Postdam operations have had deteriorating effects on a National Register property—the Charles H. Spencer paddle wheel steamboat—due to exposure. The fluctuating flows cause constant wetting and drying of the steamboat that has led to its deterioration. Low flows have allowed additional damage to the steamboat by visitors who use parts of the steamboat (the boiler) for recreational purposes (fishing).

The 1983-86 clear-water floods were detrimental to some archeological sites. The risk of flooding remains unchanged under this alternative, and all 336 sites have the potential to be damaged or destroyed. Site-specific mitigation is possible for some sites within the river corridor. Specifics of mitigation are discussed in the documentation found in attachment 5.

Native American Traditional Cultural Properties. The river corridor has been used traditionally over hundreds or thousands of years by the native peoples of the region. The Colorado River, its tributaries, the canyons through which it flows, the canyon rims, and the mountains and plateaus that surround them form a sacred landscape that is culturally significant to the Indian Tribes with ties to Grand Canyon. Within this landscape are specific places, ranging from archeological sites to mineral collection areas, considered important for a variety of reasons by each tribe. The locations of these traditional cultural properties are sometimes closely held secrets, and it is often with reluctance that tribes reveal specific sites.

In addition to archeological sites, a number of traditional cultural properties have been identified for this EIS. However, there are additional areas whose locations have not been revealed because of their sensitive nature. In addition to the specific sacred sites or locations, other natural resources of significance are found in the Colorado River corridor. Although these resources may be linked to specific locations, some are place-independent or encompass numerous locations. They also may have spiritual meanings. Most natural resources are considered sacred by Indian Tribes, and some resources are vital for the continuation of traditional cultural practices.

In general, no action conditions have fostered the growth (over predam conditions) of many culturally important riparian plants and animals as well as many species of birds of prey. This growth is primarily due to the lack of annual scouring floods and the increase in the NHWZ vegetative community. Under no action, however, the 1983-86 floods resulted in removal of approximately 40 percent of NHWZ vegetation that had established since closure of the dam (see VEGETATION in this chapter).

Havasupai.—Many traditional cultural properties are associated with the Havasupai Tribe. Locations that contain archeological remains have been discussed above. In addition to these places, traditional cultural properties and resources also have been identified. Under the No Action Alternative, degradation would continue to the archeological sites identified as ancestral for the Havasupai. In addition, degradation of the entire ecosystem would be allowed to continue, seriously impacting Havasupai uses of the area.

Hopi.—The entire Grand Canyon and its immediate surroundings are of universal importance to the Hopi people. Specific places and concepts linked to Grand Canyon are referenced in daily prayers and play a profound role in Hopi ceremonial activities. The very presence of Glen Canyon Dam and its effect on the environment have a detrimental influence on Hopi lifeways. It is Hopi belief that if the natural and cultural elements of the canyon are being damaged by dam operations, daily prayers also are damaged and less effective. Hopis believe that natural erosion is an integral process in the Grand Canyon environment, but this is distinguished from the erosion caused by dam operations. Hopis believe that Glen Canyon Dam should be operated to minimize humanmade erosion.

Within the canyon, both natural and cultural features are considered important. All springs are considered sacred to the Hopi people. Also sacred are the Hopi Salt Mines and the sand at its base. All biological resources are considered important, especially birds with yellow feathers, endangered and candidate species, aquatic organisms, and vegetation found in marsh and riparian habitats—especially reeds, willows, and cattails.

Under the No Action Alternative, continued degradation of the canyon's resources of Hopi concern would occur. Although considered a rare event, the situation that resulted in the floods of 1983-86 would be allowed to continue. Damage to archeological sites would continue, as previously discussed. Riparian habitat for the yellow birds would decline in quality and quantity. Ecological stability would not occur. Marsh habitat for reeds and cattails would continue to degrade. Although during normal operations the immediate area around the Hopi Salt Mines would not be affected, the sand at the base eventually would be lost.

Some endangered species may be impacted by no action. For example, opportunities for humpback chub to recover from jeopardy would not occur, and existing chub populations may decline further; wintering bald eagles at Nankoweap Creek may decline due to lack of food resources (inability for trout to access tributaries); willow flycatcher populations may continue to decline due to lack of habitat.

The Hopi people believe that during their migration their ancestors left behind archeological sites, potsherds, rock art, and other archeological materials to serve as markers that the Hopi people had fulfilled their pact with *Ma' saw*. Thus, the archeological record serves to validate the cultural claim of the Hopi people to the landscape. The erosion of archeological sites in Grand Canyon would diminish the cultural ability of the Hopi people to interpret their past as evidenced by these markers. Under the No Action Alternative, the erosion that would damage archeological sites and sacred ancestral graves remains a threat. The No Action Alternative would be more damaging to resources of Hopi concern than any other alternative except the Maximum Powerplant Capacity Alternative.

Hualapai.—Many traditional cultural properties are associated with the Hualapai Tribe. Those locations that contain archeological remains have been discussed previously. Traditional cultural properties not associated with archeological remains also have been identified and are discussed below.

Resources found in the natural environment are considered traditional cultural properties by the Hualapai people. The deserts, plateaus, mountains, and valleys are considered important, as well as the botanical resources and wildlife. Plants have uses both for horticultural and medicinal purposes. Specific locations within the canyon have significance as places for religious or ceremonial activities.

Specific plants important to the Hualapai people include cattails, willows, arrowweed, mesquite, catclaw, agave, and yucca. Bighorn sheep, deer, elk, and a variety of other mammals are resources traditionally used by the Hualapai. Numerous side canyon locations, along with mineral collection areas and springs, are sacred places to the Hualapai. Springs, such as Honga, and collection areas for minerals, such as hematite, also are sacred places.

Under the No Action Alternative, degradation of the river corridor would continue and result in the continued loss of archeological places identified as ancestral to the Hualapai, along with the continued loss of resources considered traditional cultural properties. All resources— natural, cultural, and spiritual—would be impacted by this alternative.

Navajo.—Navajo residents of Grand Canyon area have identified many separate localities that represent traditional cultural properties. In addition to archeological sites and the larger landscape of which they are a part, more specific places of traditional significance also have been identified. Twelve such places are within the area of potential impact, and many more have been identified immediately outside the impact area. These places include various kinds of trails or routes into the canyon, the salt mines, prayer offering locations, river crossings, places associated with stories of holy beings or historically significant figures, plants used for medicinal and subsistence purposes, minerals used for secular or sacred purposes, winter camps, cornfields, livestock grazing areas, places where people hid from enemies, areas where people lived during drought years, and places in side canyons where water may be collected.

Specific plants and animals in and around Grand Canyon also are important to the Navajo people. Plant life of importance includes beargrass, agave, mormon tea, mullen, cholla and prickly pear cactus, snakeweed, datura, filaree, four o'clocks, dogweed, narrow leaf, and banana yucca. Important wildlife (and habitat) include bighorn sheep, deer, turkey, coyote, beaver, fox, and mountain lion. Birds such as red-tailed hawks, owls, eagles, and falcons also are considered important to the Navajo people.

The existence of cultural resources, including plants and wildlife in the Colorado River corridor, depends on the beaches and terraces that support them. These resources are components of a dynamic ecosystem that erodes and rebuilds as part of a natural process. Cultural resources are exposed, buried, and even eroded away as part of this process. Their natural erosion and disappearance are not considered negative impacts by the Navajo Nation. Human-induced changes that result in the loss of resources are not viewed as part of this natural process, however. The Navajo Nation believes that the negative impacts of human interference with natural processes must be controlled. While the No Action Alternative has only a minimal direct impact on cultural resources important to the Navajo Nation, the lack of flood control makes this alternative potentially more damaging than those alternatives with flood protection.

Southern Paiute.—Hundreds of archeological sites, several traditional cultural properties, and numerous other areas of cultural significance to the Southern Paiute are located within the Colorado River corridor. Some traditional sites have already been lost due to erosion. Other sites are near the water, and under alternatives that allow unrestricted fluctuating flows these sites would be destroyed. Southern Paiute people believe that their ancestors left things in the river corridor for a purpose. They believe that those things will return to the earth naturally, but impacts on them resulting from dam operations should be stopped. Southern Paiutes differentiate between impacts that are due to natural causes and those that are the result of human activities.

Sixty-eight species of plants found within the canyon were used traditionally and are currently used for food, medicine, ceremony, construction, and other purposes. Younger generations continue to be instructed about their traditional uses. The Southern Paiutes support alternatives that will minimize flooding, erosion, and removal of vegetation. Southern Paiute people believe that under the unrestricted fluctuating flow alternatives many plants would continue to be negatively affected.

Southern Paiutes also are concerned with the effects of water release policies on tourist behavior in the Colorado River corridor. As the water from Glen Canyon Dam erodes more and more beaches, tourists are forced to camp at fewer and fewer places. When tourists camp, they walk around and pick up Native American artifacts and trample, clear, and pick vegetation. Under the No Action Alternative, the beaches available to tourists would continue to disappear, and impacts to cultural resources at the remaining beaches would grow worse. The Southern Paiutes support alternatives that reduce erosion to beaches and tourist camping spots and recommend that problems caused by tourists be addressed.

Zuni.—The Zuni Tribe has many ties to the canyon, and many ancestral archeological sites—as well as other locations and resources of traditional and cultural importance—are known to be located along the Colorado River and the LCR. Under the No Action Alternative, serious degradation of ancestral archeological sites, traditional cultural properties, and other culturally important resources would occur. The Zuni Tribe is in the process of identifying cultural resources of importance to the tribe within the study area. When these studies are completed, the Zuni Tribe will be able to more fully assess impacts to the resources and traditional and cultural values.

Maximum Powerplant Capacity Alternative

Under this alternative, degradation of **archeological sites** and **traditional cultural properties and resources** would be the same or worse than under no action. Loss of sediment and channel margin deposits would continue. More frequent high flows of up to 33,200 cfs would accelerate the loss of sediment from the system, hastening the loss of cultural resources. Arroyo-cutting through high terraces, which is linked to archeological site erosion, would continue.

Impacts to all 336 archeological sites identified within the river corridor would be likely to occur. Impacts to traditional cultural properties of all tribes also would continue under this alternative (table IV-13). For example, impacts to the Hopi Salt Mines would continue due to the lack of flood frequency reduction measures. With increased high flows and wider fluctuations, it is possible that the sand at the base of the mines would be eroded away—a serious impact to the Hopi people. Similar impacts would occur to other resources identified as traditional cultural properties for all the tribes. Impacts on traditional cultural resources follow the patterns discussed in those sections of this document (see FISH, VEGETATION, WILDLIFE AND HABITAT, and ENDANGERED AND OTHER SPECIAL STATUS SPECIES in this chapter).

With the increased range of flows under this alternative and no reduction in flood frequency, there would be a high probability of net loss of sediment in the system. This loss would likely result in damage to traditional cultural properties and resources and would create conditions similar or more adverse than those under the No Action Alternative.

Restricted Fluctuating Flows

Degradation of **archeological sites** and **traditional cultural properties and resources** would decrease from no action primarily due to flood frequency reduction measures. The probability of net loss of sediment would be less than under the No Action or Maximum Powerplant Capacity Alternatives. Arroyo-cutting of high terraces, which is linked to archeological site erosion, would continue. Flood control measures included in all restricted fluctuating and steady flow alternatives would provide increased protection of these resources.

Physical cultural resources within the river corridor are linked to sediment. Flows that cause a net decrease in stored sediment also will hasten deterioration of the cultural resources dependent on it. Since Glen Canyon Dam blocks the downstream passage of sediment, typical maximum flows less than 20,000 to 22,000 cfs appear to provide the best opportunity for a net positive balance of sediment in the system. Minimum flows of 8,000 cfs or more would provide the best protection for the Charles H. Spencer steamboat located upstream from Lees Ferry.

Site-specific mitigation would be required for all sites considered to be directly, indirectly, or potentially impacted by these alternatives. Specifics of mitigation actions are included in the section 106 compliance, found in attachment 5.

Existing impacts to traditional cultural properties would be reduced under the restricted fluctuating flow alternatives because of the flood frequency reduction measures added to these alternatives. These are measures which would lengthen the time between scouring floods (from an average 1 in 40 years to 1 in 100 years), resulting in increased growth and stability of NHWZ riparian habitat.

High Fluctuating Flow Alternative

Under this alternative, degradation of **archeological sites** would be less than under no action because of the flood frequency reduction measures discussed above. However, high fluctuating flows could continue to cause net loss of sediment, similar to the No Action and Maximum Powerplant Capacity Alternatives. Maximum hourly flows would be greater than 21,000 cfs 62 percent of the time and greater than 25,000 cfs 47 percent of the time. The relatively high frequency of these flows may not allow sediment to accumulate in the river channel. Infrequent beach/habitat-building flows between 41,500 and 45,000 cfs would help maintain sandbars, which protect high terraces and archeological sites. Arroyo-cutting of high terraces, which is linked to archeological site erosion, would continue. Because of the reduced risk of flooding, impacts are likely to occur at 263 sites identified as having direct, indirect, or potential impacts. Sites not located on river sediment (73) would not be impacted.

Impacts to **traditional cultural properties** would be less than under no action due to flood frequency reduction measures. Traditional cultural resources would remain at a level similar to no action.

Moderate Fluctuating Flow Alternative

Degradation of **archeological sites** would continue under this alternative but would be lessened due to reduced probability of net sediment loss and the adoption of flood control measures. Although impacts on these resources would occur, fewer sites would be potentially impacted under this alternative as compared to no action. Maximum hourly flows would be greater than 21,000 cfs 18 percent of the time and greater than 25,000 cfs 6 percent of the time. This would likely allow sediment to accumulate in the river during most years.

Habitat maintenance and beach/habitat-building flows would help maintain sandbars, which protect high terraces and archeological sites. Impacts on those sites (33) that have been directly impacted by postdam operations would continue; however, the likelihood of additional effects on directly and indirectly impacted sites (124) would lessen. Effects on potentially damaged sites (106) that lie within predam river deposits would continue, although the risk is less than under no action.

Traditional cultural properties within the river corridor would continue to be impacted under this alternative, although impacts would be less than under no action. However, with lower maximum releases, fewer impacts would occur to resources valued by the various Indian Tribes. Those biological (riparian habitat, wildlife) and mineral resources that have been identified as important **traditional cultural resources** would be protected or enhanced to a greater extent under the controlled flows of this alternative than under no action.

Modified Low Fluctuating Flow Alternative

Under this alternative, degradation of **archeological sites** would continue but would be lessened compared to no action due to reduced probability of net sediment loss and reduced flood frequency. Maximum hourly flows would be greater than 21,000 cfs 4 percent of the time and greater than 25,000 cfs 2 percent of the time. This would likely allow sediment to accumulate in the river during most years. Habitat maintenance and beach/habitat-building flows would help maintain sandbars, which protect high terraces and archeological sites. Impacts on those sites directly impacted by postdam operations would continue; however, the rate of additional impacts on those directly and indirectly impacted sites would lessen. Effects on potentially impacted sites that lie within predam river deposits would continue.

Traditional cultural properties within the river corridor would continue to be impacted under this alternative, although impacts would be less than under no action. However, with lower maximum releases, fewer impacts would occur to resources valued by the various Indian Tribes. Those biological (riparian habitat, wildlife) and mineral resources that have been identified as important **traditional cultural resources** would be protected or enhanced to a greater extent under the controlled flows of this alternative than under no action.

Interim Low Fluctuating Flow Alternative

Under this alternative, degradation of **archeological sites** would continue but would be lessened compared to no action due to reduced probability of net sediment loss and reduced flood frequency. Maximum hourly flows would be greater than 21,000 cfs 4 percent of the time and greater than 25,000 cfs 2 percent of the time. This would likely allow sediment to accumulate in the river during most years. Beach/habitat-building flows between 30,000 and 45,000 cfs would help maintain sandbars, which protect high terraces and archeological sites. Impacts on those sites directly impacted by postdam operations would continue; however, the likelihood of additional impacts to those directly and indirectly impacted sites would lessen. Effects on potentially impacted sites that lie within predam river deposits would continue.

Traditional cultural properties within the river corridor would continue to be impacted under this alternative, although impacts would be less than under no action. However, with lower maximum releases, fewer impacts would occur to resources valued by the various Indian Tribes. Those biological (riparian habitat, wildlife) and mineral resources that have been identified as important **traditional cultural resources** would be protected or enhanced to a greater extent under the controlled flows of this alternative than under no action.

Steady Flows

Impacts on cultural resources would vary under the steady flow alternatives. Degradation of **archeological sites** and **traditional cultural properties** would decrease from no action primarily due to flood frequency reduction measures. The probability of net loss of sediment would be less than under the No Action or Maximum Powerplant Capacity Alternatives. Arroyo-cutting of high terraces, which is linked to archeological site erosion, would continue. Flood control measures would provide a potential measure of increased protection to these resources.

Physical cultural resources within the river corridor are linked to the sediment resource. Flows that accelerate sediment erosion also would hasten the deterioration of cultural resources. Flows less than 20,000 to 22,000 cfs appear to provide the highest probabilities for a positive net sand balance in the system. Minimum flows greater than 8,000 cfs would provide the best protection for the Charles H. Spencer steamboat, along with providing a relatively stable sediment base level.

Those biological (riparian habitat, wildlife) and mineral **traditional cultural resources** that have been identified as important to Indian Tribes would be protected to a greater extent under the steady flow alternatives than under no action.

Site-specific mitigation would be required for all sites considered directly, indirectly, or potentially impacted by these alternatives. Specifics of mitigation actions are included in section 106 compliance, found in attachment 5.

Existing Monthly Volume Steady Flow Alternative

Degradation of **archeological sites** would continue under this alternative but would be less than under no action due to the higher probabilities of a positive sand balance in the system. Flows would be expected to exceed 20,000 cfs 7 to 17 percent of the time. This would likely allow sediment to accumulate in the river during most years. Beach/habitat-building flows between 26,300 and 45,000 cfs would help maintain sandbars, which protect high terraces and archeological sites. Effects on those sites that have been directly impacted by postdam operations would continue; however, the likelihood of additional impacts on those sites and indirectly impacted sites would lessen. Effects on potentially impacted sites that lie within predam river deposits would continue.

Impacts on **traditional cultural properties** under this alternative generally would be less than under no action because sediment loss would be slowed. Similarly, **traditional cultural resources** would tend to be enhanced by the greater security of the riparian zone due to reduced flood frequency, positive sediment balance, and potentially greater area of riparian habitat.

Seasonally Adjusted Steady Flow Alternative

Under this alternative, degradation of **archeological sites** would continue but would be less than under no action due to the higher probabilities of a positive sand balance in the system. Effects on those sites which have been directly impacted by postdam operations would continue; however, the likelihood of additional impacts on those sites and indirectly impacted sites would lessen. Effects on potentially impacted sites that lie within predam river deposits would continue. Flows would be expected to exceed 20,000 cfs 5 to 27 percent of the time. This would likely allow sediment to accumulate in the river during most years. Habitat maintenance and beach/habitat-building flows would help maintain sandbars, which protect high terraces and archeological sites.

Impacts on **traditional cultural properties and resources** would be the same as those described for the Existing Monthly Volume Steady Flow Alternative.

Year-Round Steady Flow Alternative

Degradation of **archeological sites** would continue under year-round steady flows but would be less than under no action due to the higher probabilities of net positive sand balance in the system. Effects on those sites directly impacted by postdam operations would continue; however, the likelihood of additional impacts on those sites and indirectly impacted sites would lessen. Effects on potentially impacted sites that lie within predam river deposits would continue. Flows would be expected to exceed 20,000 cfs 8 to 12 percent of the time, allowing sediment to accumulate in the river during most years.

Beach/habitat-building flows between 21,400 and 45,000 cfs would help maintain sandbars, which protect high terraces and archeological sites. The probability of a net positive sand balance would be very high. Although sediment deposition would not be substantial enough to increase the stability of the sediment deposits, erosion of terraces in direct contact with the river would be reduced.

Impacts on **traditional cultural properties and resources** would be the same as those described for the Existing Monthly Volume Steady Flow Alternative.

AIR QUALITY

Issue:

How do dam operations affect other electrical production in the area, including those methods that have impacts on AIR QUALITY?

Indicators:

Sulfates in **Grand Canyon air**
Tons of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) in **regional air**

Impacts on air quality in the immediate Grand Canyon vicinity and across the region served with Salt Lake City Area Integrated Projects power were evaluated for each alternative. Although hydroelectric power production at Glen Canyon Dam has no direct influence on air quality, a change in its operations would affect the electrical power system of which it is a part. Glen Canyon Dam historically has been used to produce peaking power. If it were used as a baseload or base-assist facility instead, another source of peaking power would be required to generate the amount of peaking power that could not be compensated for through conservation or renewable energy technologies. If the alternative source of power used fossil fuel, there would be a net change in system emissions, either in the region or somewhere in the Salt Lake City Area Integrated Projects marketing area. Fossil fuels contain hydrocarbons, whose combustion can result in emissions of such atmospheric pollutants as sulfur dioxide and nitrogen oxides.

Natural gas combustion turbines are a common type of facility used to produce peaking power. Like hydroelectric generators, gas combustion turbines can be used to follow load during peak periods of demand. Natural gas is a hydrocarbon fuel, but is relatively clean compared to coal. Although it might be necessary to use gas turbines to replace peaking power if dam operations are changed, it is also likely that Glen Canyon Powerplant would be used to replace power production at baseload or base-assist facilities, many of which burn coal. It is also possible that a change in operations could influence the schedule for adding new baseload facilities to the power system (see HYDROPOWER in this chapter). Emissions from coal combustion usually have components of SO_2 and NO_x in greater amounts than emissions from natural gas.

Analysis Methods

This EIS considered SO_2 and NO_x emissions and factors such as the Clean Air Act provisions mandating a national ceiling on such emissions. Information on other substances—such as carbon monoxide and particulates—was not available for this EIS. However, numbers for SO_2 and NO_x can be considered representative of changes in carbon monoxide and particulate concentrations.

Impacts to regional air quality were evaluated as part of the power systems analysis for the draft EIS. This analysis showed less than a 1-percent change in emissions under any alternative. However, it was later found that the analysis did not correctly account for the reduction in emissions at other locations within the region. The analysis procedure was corrected, and the preferred alternative was reanalyzed for this final EIS.

The analysis does not specify the location and concentration of atmospheric pollutants. Emissions could have an influence on the air quality in Grand Canyon and the other national parks on the Colorado Plateau, all of which are class I areas (chapter III, AIR QUALITY). However, the source of emissions would not necessarily be in the immediate vicinity; it could be elsewhere in the load control area. If there were not enough peaking power capacity within the region and it became necessary to construct a new facility, it would be necessary to conduct a new source review. However, in this analysis it is not as important to know the source as it is to understand the relative tradeoffs of different alternatives and their influence, in terms of emissions and their relative influence on air quality.

The first 5 years of operation under each alternative and how that operation would influence air quality are defined as short-term impacts. Since modeling results did not provide emissions estimates for a 5-year period, this analysis looks at what short-term system expansion might be needed and how that expansion would influence, in qualified terms, system emissions.

For the long-term period of analysis, emissions representing a 50-year period and across the regional power grid area are evaluated. This emissions analysis includes assumptions for power system expansion plans. Emissions would vary by alternative because each would require a different power system expansion plan. The impacts are speculative in that changes over the 50-year period are possible in power generation technology, demand for power, public attitudes, and political and economic climates.

Summary of Impacts: Air Quality

The geographic area of potential impacts would be the same as for hydropower—the Salt Lake City Area Integrated Projects service area, which includes all or part of Wyoming, Utah, Colorado, Arizona, Nevada, and New Mexico.

Glen Canyon Dam is in the same power system as the Navajo Generation Station, which was identified as a source of **Grand Canyon air quality** problems and is scheduled to be modified to reduce emissions, beginning in 1995. Navajo Generating Station is independent of Glen Canyon Dam operations, and its modifications will be made regardless of which EIS alternative is implemented. Grand Canyon air quality would likely improve due to the modifications at Navajo Generating Station no matter which alternative is selected.

Table IV-14 presents impacts on air quality that would likely result from each alternative. The

Table IV-14.—Summary of anticipated impacts on AIR QUALITY during the 50-year period of analysis by alternative

AIR QUALITY	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Grand Canyon air quality									
Sulfates resulting from SO_2 emissions at Navajo Generating Station	Reduced to EPA-mandated levels by 1999	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action	Same as no action
Regional air quality[1]									
SO_2 total emissions (thousand tons)	1,960	Same as no action	Slight reduction	Slight reduction	Slight reduction	Slight reduction	Slight reduction	Slight reduction	Slight reduction
NO_x total emissions (thousand tons)	1,954	Same as no action	Slight reduction	Slight reduction	Slight reduction	Slight reduction	Slight reduction	Slight reduction	Slight reduction

[1] Under all alternatives, changes in SO_2 and NO_x emissions would be less than plus or minus 1 percent compared to no action.

amount of peaking power that would need to be replaced varies under each alternative. The net effect on **regional air quality** under all alternatives would be a slight reduction in emissions.

Unrestricted Fluctuating Flows

No Action Alternative

Glen Canyon Powerplant is used as a peaking power facility, but it is part of a regional power system that is made up of both hydropower and fossil fuel plants. Power production at the dam varies annually based on the volume of water available to pass through the turbines. It is anticipated that demand for power from the system will increase, but most short-term increases in demand can be absorbed by greater energy efficiency. It is also anticipated that, by as early as 1995, gas combustion turbines will be added to the power system to replace older and inefficient facilities. Since natural gas is a cleaner fuel than coal, these additions probably will reduce system emissions over the short term.

In the long term, the need for additional baseload coal-fired capacity is anticipated. The emissions of the power system for the entire period would be approximately 2 million tons of SO_2 and 2 million tons of NO_x.

Maximum Powerplant Capacity Alternative

Power production under the Maximum Powerplant Capacity Alternative would be essentially the same as that under the No Action Alternative.

Restricted Fluctuating and Steady Flow Alternatives

The restricted fluctuating and steady flow alternatives would reduce the amount of electrical energy produced during the day and correspondingly increase the amount of energy produced at night. This would mean that as demand for electrical energy increases, additional powerplants would be needed sooner than under no action. New powerplants would produce less emissions than existing plants because of today's more restrictive emissions standards and because some of these new powerplants would burn natural gas.

Although total emissions from all new and existing powerplants may increase during the day, there would be an even greater reduction of emissions at night because Glen Canyon Powerplant and additional new, more efficient powerplants would be producing more power at night. Therefore, the net effect on **regional air quality** under all restricted fluctuating and steady flow alternatives would be a slight reduction in emissions.

Additional power modeling studies completed since the draft EIS for the preferred alternative support this conclusion. The analysis predicted that total emissions of SO_2 would be reduced by 100,000 tons, and emissions of NO_x would be reduced by nearly 80,000 tons over a 20-year period relative to the No Action Alternative.

RECREATION

Issue:

How do dam operations affect RECREATION in the study area?

Indicators:

Fishing trip attributes, safety, and access
Day rafting trip attributes and access
White-water boating trip attributes, camping beaches, safety, and wilderness values
Lake activities and facilities
Net **economic value** of recreation

Discharge from Glen Canyon Dam affects recreation through its influence on flow-sensitive attributes or through changes in the recreation environment. Impacts on recreation would range from regional to international in scope.

Analysis Methods

Recreation would be impacted immediately by changing discharge, and impacts would occur over both the short and long term. Water years 1989, 1987, and 1984 are used for analyzing impacts under low, medium, and high annual water release conditions. For fluctuating flow alternatives, the magnitude of impacts associated with daily fluctuations for low, moderate, and high release years are compared using certain representative days in those years (figure II-7). Typical conditions, rather than exceptional ones, are evaluated under each alternative. Impacts may be similar for most alternatives during high water years, while quite different during low and moderate water years.

Impacts on the recreation environment, the resource upon which the activity is focused or dependent, are long term (20 to 50 years). Analyses of impacts on resources upon which recreation depends are discussed elsewhere in this chapter (primarily SEDIMENT, FISH, and VEGETATION) and will be only referenced in this section.

Summary of Impacts: Recreation

The impacts of the alternatives on recreation activities are summarized in table IV-15. Numerical values are listed where possible; otherwise, qualitative assessments are made. Impact assessments for many activities are based on rankings of alternative operational scenarios in a study of visitor preferences by Bishop et al. (1987). Each alternative was ranked as more or less favorable for recreation overall and for each indicator activity. As discussed in chapter III, indicator activities are fishing, day rafting, white-water boating, and lake facilities and activities.

Effects of habitat maintenance flows are discussed under the three alternatives that include them.

Based on preferences determined by the Bishop et al., study, net economic values also were estimated for each alternative. Net economic benefits are discussed under "Economics of Recreational Use" at the end of this section.

Fishing

Fishing trip quality for most anglers in the Glen Canyon reach is highest during moderate, steady discharges because they believe such discharges improve several attributes of fishing trips.

Anglers using the Glen Canyon trout fishery place a high value on catching large fish (chapter III, RECREATION). It is believed that under the fluctuating flow alternatives with a wide range of daily fluctuations, trout would be less likely to reproduce and survive until they reach trophy size. Under the Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives, the potential for catching large fish would increase, and, therefore, fishing trip quality also would have the potential to increase. The steady flow alternatives are believed to have the greatest potential for benefiting aquatic productivity, which could result in trophy-size fish.

Rapid stage change puts wading anglers in Glen Canyon at risk of inundation. If their waders are filled with water, it becomes difficult for them to wade or swim toward shore. In the alternatives without ramp rate restrictions, stage can increase within 20 minutes by 0.62 foot at Lees Ferry and by 0.88 foot at the dam (the latter is more representative of the reach). This risk would be reduced under the alternatives with ramp rate restrictions and would be eliminated in the steady flow alternatives, as shown in table IV-16. During high water volume years, fluctuations would be at a minimum under all alternatives. High water velocity may present hazards to wading anglers, but they also would be able to assess risk before putting themselves in a hazardous position.

There are 18 camping beach sites potentially available in Glen Canyon; only 6 of these are formally designated campsites. Six others are available only at discharges of less than 15,000 cfs. These sites would be available in the Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives during winter months of low discharge years.

Downstream in the Grand Canyon wild fishery, angler safety is not believed to be a major issue,

Table IV-15.—Summary of anticipated impacts on RECREATION by alternative

RECREATION	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Fishing									
Trip quality (fishing success)	Influenced by daily fluctuations	Same as no action	Same as no action	Minor increase	Moderate increase	Moderate increase	Potential to become major increase	Moderate increase	Major increase
Glen Canyon blue ribbon trout fishery quality	Influenced by low flows and fluctuations	Negligible decrease	Negligible increase	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase
Angler safety	Potential danger	Same as no action	Same as no action	Moderate improvement	Moderate improvement	Moderate improvement	Major improvement	Major improvement	Major improvement
Day rafting									
Navigation past 3-Mile Bar	Difficult at low flows	Same as no action	Negligible improvement	Major improvement	Major improvement	Major improvement	Major improvement	Major improvement	Major improvement
White-water boating									
Trip quality	Influenced by range of daily fluctuations and low flows	Same as no action	Same as no action	Moderate increase	Potential to become major increase	Potential to become major increase	Major increase	Major increase	Major increase
Wilderness values	Influenced by range of daily fluctuations	Same as no action	Minor increase	Moderate increase	Moderate to potential to become major increase	Moderate to potential to become major increase	Major increase	Major increase	Major increase
Safety and handicapped accessibility	High risk at very high and very low flows	Same as no action	Negligible improvement	Minor improvement	Minor improvement	Minor improvement	Moderate improvement	Potential to become major improvement	Major improvement
Camping beaches average area at normal peak stage	Less than 7,720 square feet	Same as no action	Same as no action	Minor increase	Minor increase	Minor increase	Major increase	Potential to become major increase	Major increase
Lake activities and facilities									
Lake Powell facilities average seasonal adjustment cost ($)	21,600	21,600	21,600	21,600	21,600	21,600	21,600	14,400	21,600
Upper Lake Mead navigability	Primarily influenced by lake elevation	Negligible effect	Minor effect	Minor effect	Minor effect	Moderate effect	Moderate effect	Moderate effect	Minor to moderate effect
Economics									
Change in equivalent annual net benefit (1991 nominal $ million)	0	0	0	+0.4	+3.7	+3.9	+3.9	+4.8	+2.9
Change in net present value (1991 $ million)	0	0	0	+4.6	+43.3	+45.6	+45.6	+55.0	+23.5

Table IV-16. -Stage change in the Glen Canyon reach by alternative

Alternative	Stage change per day at Lees Ferry (feet)	Maximum 20-minute stage change at Lees Ferry (feet)	Maximum 20-minute stage change at Glen Canyon Dam (feet)
No action	4.5	0.62	0.88
Maximum powerplant capacity	4.5	0.62	0.88
High fluctuating flow	4	0.62	0.88
Moderate fluctuating flow	2.5	0.24	0.50
Modified low fluctuating flow	1.5	0.10	0.30
Interim low fluctuating flow	1.5	0.10	0.30
Existing monthly volume steady flow	0	0	0
Seasonally adjusted steady flow	0	0	0
Year-round steady flow	0	0	0

primarily because most fishing activities take place from boats or shore. Historically, trout spawning success has been adequate to maintain the downstream trout fisheries without depending on stocking or restrictive management of fishing activities. Trout population success would likely continue under all alternatives. This issue is discussed in this chapter under FISH and will not be tracked further in this section.

Day Rafting

Boaters in the Glen Canyon reach, most of whom are anglers, have difficulty navigating 3-Mile Bar when discharge is 3,000 cfs or less (U.S. Department of the Interior, 1990). Most boaters are unable to move up or downstream, and some of those attempting to navigate the channel hit rocks and sustain boat and motor damage. Difficulties typically occur during morning hours, a popular fishing time.

Boaters would have navigation problems under the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives. The other fluctuating flow alternatives, which have minimum flows of 5,000 cfs, would eliminate navigation and safety impacts for most day rafters and other boaters. Steady flow alternatives should make 3-Mile Bar passable to all boaters.

Day rafters in Glen Canyon benefit slightly by launching at the dam rather than at Lees Ferry. However, there is no significant preference by users as to the origin of their trip (Bishop et al., 1987), so impacts would be negligible. All alternatives are thought to have similar influences on day rafting, and habitat maintenance flows are unlikely to have any impact on the quality of day rafting below Glen Canyon Dam. Since this is not a significant issue, it will not be tracked further.

White-Water Boating

White-water boaters prefer moderate fluctuations and steady flows because of their influence on important trip attributes, including itinerary, character of rapids, wilderness values, and boat management at camp. White-water boaters were asked to rank several operational scenarios in the Bishop et al. (1987) study. Of the EIS alternatives, the steady flow alternatives would be most similar to the preferred scenarios. Fluctuating flow alternatives with daily range and ramp restrictions and 5,000-cfs minimum flows would be more tolerable than those without.

Wilderness values are influenced by daily fluctuating flows. When the river undergoes wide daily fluctuations, most river-runners are aware of these fluctuations and feel they make the trip seem less like a natural setting (Bishop et al., 1987). These fluctuations are unlike the predam fluctuations that resulted from tributary and side canyon flooding. Fewer river-runners would be aware of the daily fluctuations under alternatives with more restricted daily ranges. Noticeable fluctuations would decrease with distance below the dam because of wave transformation (see chapter III, WATER). Under the steady flow alternatives, more river-runners would feel that the river provided a more natural setting than fluctuating flows, thus improving wilderness values.

An index of white-water accident risk, developed by Brown and Hahn (1987), was used to compare safety of alternatives. Specific assessments were made for private and commercial groups. The No Action and Maximum Powerplant Capacity Alternatives have the highest overall risk index because they would have more time at low flows, when accident potential is great for commercial motor and small oar-powered craft. The probability of people going overboard is highest at discharges that exceed powerplant capacity (Brown and Hahn, 1987). Risk would be reduced most under the steady flow alternatives, while the restricted fluctuating flow alternatives would reduce risk half as much. Over the long term, under all alternatives including no action, debris flows would continue to be a factor in boater safety. All alternatives improve safety relative to no action because of higher minimum flows.

Handicapped accessibility was raised as an issue in scoping and is a concern for NPS, which issues preferential permits for trips with handicapped individuals. Low flows (less than 5,000 cfs) increase the potential for having to walk handicapped individuals around a rapid, while extremely high flows increase the potential for a passenger and rescuer going overboard. Effects on accessibility under each alternative follow the same pattern as accident risk above.

The number, size, and character of camping beaches in Grand Canyon have a direct effect on the total recreational capacity of the river corridor and the experience for white-water recreationists. The absolute limits on numbers of people are determined by the reaches in which campable beaches are critically limited. Under the fluctuating flow alternatives, distribution of sites within powerplant capacity would be 0.7 site per mile in critical (narrow) reaches and 1.1 sites per mile in noncritical (wide) reaches. Steady flow alternatives would have 0.9 site per mile in critical reaches and 1.1 sites per mile in noncritical reaches. The number of sites is not fixed through time but is affected by sediment erosion and deposition and vegetation encroachment. These factors vary among alternatives (see SEDIMENT and VEGETATION in this chapter).

The size of a particular camping beach would be highly variable depending on flow, as determined by the maximum daily discharge. In most years, campable area would average 7,720 square feet or less under the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives; more than 7,720 square feet under the restricted fluctuating flow alternatives; and up to 9,200 square feet under the steady flow alternatives. Site size is not fixed through time but is affected by sediment erosion and deposition and vegetation encroachment (see SEDIMENT and VEGETATION in this chapter).

Fluctuating flows would influence mooring quality, causing boat management problems and stranding. Under the fluctuating flow alternatives, mooring would be fair to good at 64 percent of camping beaches compared to 92 percent fair to good under the steady flow alternatives.

The reach below Diamond Creek (RM 225 to RM 260) is extremely critical; 11 beaches currently are available—a site distribution ratio of only 0.3 beach per mile. Studies relating campsite availability to various discharges are not being performed on this part of the river. Because a negligible amount of the campable areas would be available below the high water line and fluctuations would attenuate downstream, it can be assumed that any difference in campsite availability due to discharge levels would be minor to negligible. In general, however, the availability and carrying capacity of camping beaches below Diamond Creek would be assumed to follow the same response trends under fluctuating and steady flow alternatives as beaches in other Grand Canyon reaches, and they will not be treated further in this analysis.

Camping area losses due to erosion and/or vegetation overgrowth have been recorded (Ross, written communication, 1992). To what degree this is attributable to dam operations is being studied by the Hualapai Tribe. A comparison of campable area under the various alternatives is shown in table IV-17.

It would be difficult to project the number of camping beaches that would exist under each alternative over the long term. However, sediment storage and active sandbar height were used to indicate the relative potential for maintaining and rebuilding camping beaches over the long term. After the high flows of 1983, more beaches were present than had been in 1975 (figure III-38). Most of the increase probably is evidence of beach-building, meaning many sites are resilient and can be maintained through either habitat maintenance or beach/habitat-building flows. However, some beaches would be lost under all alternatives due to site characteristics and the presence of the dam. Vegetation clearing may be an option for maintaining some camping beaches where encroachment is a factor.

Floodflows would be more frequent under the No Action and Maximum Powerplant Capacity Alternatives, which could reduce the number of beaches, especially in critical reaches. Under the other alternatives, floods would be reduced owing to the addition of flood frequency reduction measures. Under alternatives that maintain a sediment balance, beaches would be restored to varying degrees (see chapter IV, SEDIMENT).

Vegetation encroachment likely would occur at camping beaches. However, visitor use would limit permanent expansion at popular sites under all alternatives. On less popular beaches, vegetation encroachment eventually would make the site difficult to use. If dam operations could be used to limit vegetation encroachment, consistent with ecosystem objectives, habitat maintenance and beach/habitat-building flows likely would be scheduled to do so. However, ecosystem needs are a more important consideration than camping beaches, especially since clearing vegetation is an option, and much of the encroaching vegetation is non-native. Vegetation patterns would vary by alternative and are discussed under VEGETATION, earlier in this chapter.

Lake Activities and Facilities

Lake Powell level depends on annual inflow and water deliveries. The costs to adjust facilities such as marinas, docks, and launch ramps to the lake level are approximately $1,275 per 1-foot change, $33,460 per 25-foot change, and $2 million per single adjustment of 50 or more feet (Combrink and Collins, 1992). Capacities for boating and camping depend on space, which increases with reservoir elevation. Annual fluctuations are much greater than the seasonal fluctuations that occur throughout the year (approximately 18.5 feet under no action in the 50-year analysis); thus, costs of making annual adjustments would be much greater than those for seasonal adjustments. The variability among years would be much greater than the seasonal variability among the

Table IV-17.—Comparison of campable area by alternative

Alternative	Campable area (square feet)	Number of sites per mile	
		Noncritical reaches	Critical reaches
No action	7,720	1.1	0.7
Maximum powerplant capacity	7,720	1.1	0.7
High fluctuating flow	7,720	1.1	0.7
Moderate fluctuating flow	7,720	1.1	0.7
Modified low fluctuating flow	>7,720	1.1	0.7
Interim low fluctuating flow	>7,720	1.1	0.7
Existing monthly volume steady flow	9,200	+.15	+.2
Seasonally adjusted steady flow	7,720 to 8,200	Same to +.15	Same to +.2
Year-round steady flow	9,199	+.15	+.2

alternatives (approximately 6-foot difference among the alternatives). Under all alternatives, the cost of seasonal adjustments most likely would be incremental and generally would not exceed $33,460. Between-year variability for all alternatives could result in adjustments that cost as much as $2 million.

Raising the height of the spillway gates to reduce flood frequency would infrequently increase the level of Lake Powell up to elevation 3704.5. This increase would affect facilities and facility operation at Glen Canyon National Recreation Area, although such impacts have not been fully studied.

Navigability of the Colorado River where it interfaces with upper Lake Mead is influenced by several factors including reservoir level, riverflow, and the recent release pattern and its influence on sedimentation processes. Because release patterns would vary among all alternatives, effects would vary also and are discussed under each alternative. Habitat maintenance flows are expected to have little or no effect on access through the Colorado River delta under any alternative.

Unrestricted Fluctuating Flows

No Action Alternative

Fishing. Most anglers prefer moderate, steady flows (chapter III, RECREATION). However, during low water release years, the historical water release pattern under no action has been widely fluctuating flows (chapter III, WATER). This pattern is preferred over some scenarios, such as very high (greater than 40,000 cfs) or very low (less than 3,000 cfs) steady flows.

During moderate water release years, the reduced range of fluctuations would be seen as an improvement, but not a significant one. During high water years, the range of fluctuations would be reduced because of the high volume of water released. However, such high steady discharge would not be preferred because of its negative impact on fishing success.

The effects of no action on the fishery itself parallel the effects on trout described in the FISH section of this chapter. Anglers prefer wild fish over stocked fish, but continued trout stocking would be necessary because of stranding and spawning bed exposure resulting from fluctuating flows. Dam operations limit the aquatic food base, thus limiting the trout population that can be supported by the system. Fishery managers have therefore had to limit the trout population and, in turn, restrict harvest either by reducing the creel limit or limiting angler access to the fishery. This policy may be detrimental for anglers who prefer larger bag limits but would likely continue under no action. Fishing is an activity of regional importance.

In the Glen Canyon reach, 18 camping sites potentially are available, but only 12 normally are available. The other six are low water sites that are available only when flows are at or below 15,000 cfs. Maximum daily flow would be less than 15,000 cfs 12 percent of the time.

At Lees Ferry, where most angler wading occurs, there can be more than a 4-foot stage change during the day in low water years and even more at the dam. The representative stage change over 20 minutes typically is around 0.62 foot at Lees Ferry and 0.88 foot near the dam (more representative of most of the reach). A rapid change of this magnitude would place wading anglers at risk of inundation.

Day Rafting. During periods of 3,000-cfs flows or less, few (unquantified) boaters can successfully navigate 3-Mile Bar (U.S. Department of the Interior, 1990). Because few anglers would be able to move upstream during hours they prefer, impacts are of major concern. Some of those attempting to navigate the channel hit rocks and sustain boat and motor damage. Under no action, the low end of the daily range commonly reaches 3,000 cfs between Easter and Labor Day and 1,000 cfs between Labor Day and Easter. During low water years, 1,000-cfs flows occur often.

In moderate water years, 1,000-cfs flows are less frequent; however, 3,000-cfs flows may continue to occur, especially during the spring months. Typical summer releases would be around 5,000 cfs, higher than in low water years, with the proportion of successful boat passages increasing to 75 percent during periods of minimum discharge. During high water years, the potential would diminish for both a wide range of fluctuations and extremely low flows. Boats with 10 horsepower or smaller motors would have problems getting upstream during high water years.

White-Water Boating. The impacts on white-water recreation, discussed below, typically are short term and of national and international importance.

River Trip Attributes.—Many white-water boating guides and trip leaders have expressed highest preference for either a narrow range of daily fluctuations or steady flows and lowest preference for operations similar to no action. The No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives rank lowest among alternatives.

Under no action, there are numerous impacts on white-water boating trip attributes. A majority of river-runners feel that flow fluctuations during low water release years make the river seem less natural. During low flow periods, problems with stranding, navigation, and passenger enjoyment may occur (chapter III, RECREATION). During high flow periods, travel time improves as does navigability at some rapids.

During high water years, steady flows would be closer to the preferences of most boaters, although optimum conditions occur under flows of 22,000 to around 31,000 cfs. During high water years, there is more possibility that passengers on oar-powered trips would have to walk around one of the major rapids. Campsites would become smaller, and the likelihood of camping with or near another group would be increased.

Wilderness Values.—Under no action, the range of fluctuations occurring under all but the highest water volume months (and years) would be noticed by up to 87 percent of all river-runners. Of these, 75 percent of private and 50 percent of commercial passengers feel fluctuating flows make a river trip setting seem less natural. The magnitude of the impact would likely be greatest during low water years when the range of fluctuations is greatest. It is likely that the river seems most natural during high water years, due to the lack of daily fluctuations.

White-Water Safety (Accident Occurrence).—The No Action Alternative has the highest potential of all the alternatives except the Maximum Powerplant Capacity Alternative for accident occurrence. This is due to the length of extremely low and extremely high discharge periods and would be especially true during low water years. During periods of low flow (less than 5,000 cfs), the relative risk index of having an accident would be greatest for commercial motor and small oar-powered craft (Brown and Hahn, 1987; Jalbert, 1992). During the high flow periods of the day, risk would decrease for all boat types.

During high water volume years, floodflows may occur. The probability of having an accident while running a rapid during floodflows is highest for all trips, but especially for small, oar-powered craft. No action would have the greatest overall relative level of risk. Over the long term, debris flows would continue to become a greater factor in boater safety.

Handicapped Accessibility.—Under no action, passengers potentially would have to walk around rapids during low water periods, a situation that could impact physically challenged persons. Having to walk around rapids occurs most with motor rigs and smaller oar-powered craft. During high flow periods, this problem decreases for all boat types; however, the risk of people going overboard is increased.

Floodflows increase the potential of handicapped individuals having to walk around some rapids. The overall risk of capsizing a boat is also greatest. These risk patterns are similar to those experienced by the general population, but the effects are potentially greater.

Camping Beaches.—Even though size of a particular camping beach may be highly variable owing to fluctuating flows, the amount of campable area under no action can be determined largely by the maximum discharge within the daily period. In other words, a new beach exposed during the low flow period does not provide additional camping area because it could still be inundated during the high flow period.

On typical days in low and moderate water release years, the maximum daily release would be in the range of 25,000 to 30,000 cfs. The average campsite area above this discharge would be less than 7,720 square feet (the average for 25,000 cfs), with large, medium, and small sites averaging less than 11,720; 4,950; and 2,390 square feet, respectively. During high water release years, usable campsite area would be further reduced; campable area during flows above powerplant capacity has not been quantified.

The absolute limits on the Grand Canyon's recreational carrying capacity are determined by camping beach distribution in critical (narrow) reaches. Some sites are usable at all discharges within powerplant capacity—approximately 0.7 site per mile in critical reaches and 1.1 sites per mile in noncritical reaches. Additional low water sites—approximately 0.2 per mile in critical reaches and 0.15 per mile in noncritical reaches—are not usable under no action due to range of fluctuations.

In the long term, it is expected that the number of beaches would decline to a new equilibrium value, especially in critical reaches, due to the low probability of storing sand in the system (table IV-9). This decline in camping beach numbers would reduce the canyon's carrying capacity so that the numbers of parties that could be accommodated would progressively decrease. Under no action, there would not be enough sand stored in the system to rebuild sandbars and camping beaches.

During low and moderate water years, mooring quality is poor at 36 percent of the camping beaches due to fluctuating flows and the resulting influence on boat management and stranding.

Lake Activities and Facilities. Changes in dam operations could affect lake levels—and therefore facilities and recreation activities—at both Lakes Powell and Mead.

Lake Powell Facilities.—Lake elevation may rise or decline with water deliveries, requiring adjustment of lake facilities such as marinas, docks, and launch ramps. Under no action, the median amount of seasonal change in lake elevation (50-year analysis) is approximately 18.5 feet, with minimum elevation occurring during March and maximum elevation occurring during July. Between-year variability in lake elevation is greater than seasonal variability. During successive years of high water inflow from the Upper Basin, Lake Powell can be maintained at a high level. During these periods, annual adjustment costs are low, but operators of lake facilities incur approximately $1,275 of seasonal expense for every foot of adjustment necessary.

During periods of moderate water inflow, Lake Powell elevation may drop. The approximate cost of seasonal adjustments remains the same, but the one-time cost of making an annual adjustment for lake fluctuations exceeding 25 feet is approximately $33,460. When the lake level declines more than 25 to 30 feet, capital costs increase. For every 50-foot drop in lake elevation, the capital investment is estimated to be $2 million; these between-year costs are more likely to occur during successive low water years.

Lake Powell Boating.—As the density of boats on the lake increases, so does the potential for collisions and other recreational accidents. Safe boating capacity increases as surface area increases and declines with lake elevation. At 3700-foot elevation, which would result under successive high water years, the lake has a safe boating density of approximately 17,932 boats. In moderate water years, if lake elevation dropped to around 3680 feet, safe boating density would decrease to 16,387 boats. If the reservoir level reaches 3660 feet, as it might following several low water years, safe boating density could decrease to 14,920 boats.

Lake Powell Camping.—The number of campsites the shoreline can accommodate decreases as lake elevation declines. (Boaters generally camp at the lakeshore, near their boats.) Recreational use levels ultimately would be limited by suitable campsites. Potential campsite capacity for Lake Powell at full pool would be approximately 7,360 campsites. At a 3680-foot elevation, potential campsite capacity may decrease to approximately 7,134 sites. Shoreline campsite capacity would decrease to approximately 7,105 sites at 3660-foot elevation and 6,586 sites at 3620-foot elevation.

Navigability of Upper Lake Mead/Colorado River.—High lake elevations and sediment deposition during 1983-86 caused Lake Mead to submerge all rapids through Lower Granite Gorge downstream from RM 235 (see chapter III, SEDIMENT). In 1987, Lake Mead began to recede, and a shallow river channel formed. The Colorado River delta now restricts passage into or out of the Lower Gorge within Grand Canyon. The channel also is choked by new sediment being dropped along the low-velocity river that runs through the area. Marsh habitat has spread on the delta along the channel banks. The extent and magnitude of these navigation problems have not been thoroughly investigated; however, it is known from observations that the number of takeouts at South Cove (further downlake) increases during successive low water years because navigation is difficult in Pierce basin.

During low and moderate water years, when fluctuating flows are prevalent, navigation is most difficult because the configuration of the river channel can change daily. During the low water portion of the day, navigation can be difficult where the river interfaces with flat lake water because the river channel can be shallow and sandbars sometimes are exposed. Conditions for navigation are best during high water years, when lake levels are high. Impacts are unquantified.

Maximum Powerplant Capacity Alternative

The influences of this alternative on recreational resources would be essentially the same as those that occur under no action. Recreation variables influenced under no action would likely be influenced to an even greater extent under this alternative. However, the relative difference is not supported by research; therefore, impacts of this alternative will be characterized as the same as no action.

Restricted Fluctuating Flows

Impacts to recreation under the High, Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives are described in this section. An overview of common impacts from these alternatives is presented first; specific details follow under the individual alternatives.

Under the restricted fluctuating flow alternatives, impacts on **fishing** would vary, but all would potentially reduce dependence on stocking. Because of the reduced range of fluctuations, all restricted fluctuating flow alternatives would reduce angler safety problems compared to no action, but the amounts would vary by alternative. In the Glen Canyon reach, the same number of campsites probably would exist in July and August under all restricted fluctuating flow alternatives as under no action. During low volume months, six additional sites would be usable, except under the High Fluctuating Flow Alternative.

Up to 75 percent of all **day rafting** boats should be able to navigate the 3-Mile Bar under all restricted fluctuating flow alternatives except the High Fluctuating Flow Alternative, which would be similar to no action.

The Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives would have improved impacts on **white-water boating** trip attributes and would be closer to preference than no action. The High Fluctuating Flow Alternative would have impacts on river trip attributes comparable to no action. River-runners would be aware of fluctuations under all alternatives. There likely would be a difference in the magnitude of such impacts compared to no action, but this difference has not been quantified.

The relative risk of accident occurrence would vary among the four restricted fluctuating flow alternatives from 4 to 10 percent less than under no action. The High Fluctuating Flow Alternative would be similar to no action, while the others would reduce the amount of time at low flow risk. There would be no differences among alternatives during floodflows. All alternatives improve safety relative to no action because of higher minimum flows.

Effects on handicapped accessibility would vary among the restricted fluctuating flow alternatives. Low flow risk would be greatest during low water release years under the High Fluctuating Flow Alternative.

Under all restricted fluctuating flow alternatives except high fluctuating flows, there would be numerous months when maximum discharge would not exceed 15,000 cfs and when beach availability and distribution in Grand Canyon would increase—up to 0.9 site per mile in critical reaches and 1.28 sites per mile in noncritical reaches. However, boaters using these sites would be at risk of being inundated in the event of emergency exception criteria (chapter II, "Common Elements").

The availability and distribution of beaches in Grand Canyon over the short term would be comparable to no action. Under restricted fluctuating flows, camping beaches would be dynamic but more stable than under the No Action and Maximum Powerplant Capacity Alternatives. Beach height would be lower, but the amount of riverbed sand available for deposition would increase over time (table IV-6). Sandbar heights and active widths would be greater than under steady flow alternatives, and the bar heights under Moderate and Modified Low Fluctuating Flow Alternatives would be maintained due to the habitat maintenance flows. The potential for rebuilding and maintaining camping beaches is greater than under no action, although site loss would continue in some places due to erosion and vegetation growth (table IV-10).

Enough sediment would be available under all restricted fluctuating flow alternatives to contribute toward maintaining and rebuilding camping beaches with beach/habitat-building flows. Reduced flood frequency would likely maintain beaches in critical reaches because there would be fewer floods of a magnitude to top debris fans. Managed beach/ habitat-building flows would help maintain beach distribution under all alternatives; longevity of benefits would vary by alternative. Vegetation encroachment would likely be greater than under no action, causing loss of sites over time. However, vegetation clearing remains a management option.

Mooring quality would be essentially the same as under no action—poor at 40 percent of the camping beaches—although the severity of boat stranding and mooring difficulties would decrease as the range of fluctuations decreased. Stage change would be much reduced in the summer months under the Modified Low and Interim Low Fluctuating Flow Alternatives.

Concerning **lake activities and facilities**, Lake Powell's annual water storage and surface area would be the same as under no action. As a result, the costs of making facility adjustments under most alternatives would be the same as those incurred under no action. Safe boating capacity and recreation use levels, as determined by the number of suitable campsites, also would be the same as no action under all fluctuating flow alternatives.

Navigability of upper Lake Mead under all restricted fluctuating flow alternatives would be improved compared to no action.

High Fluctuating Flow Alternative

Regarding **fishing** trip attributes, the High Fluctuating Flow Alternative would have impacts similar to no action, although the reduced ranges in daily flows would result in improvements. Management of the fishery in Glen Canyon and in Grand Canyon would be similar to no action.

The overall (relative) risk of having a **white-water boating** accident would be 4 percent less than under no action. The risk for commercial users would be approximately the same as under no action, while the risk for private users would be 12 percent less.

Moderate Fluctuating Flow Alternative

Increased reliable minimum flows (5,000 cfs) during the trout spawning season would improve **fishing** by reducing trout stranding, increasing recruitment and aquatic productivity, and reducing reliance on trout stocking.

Habitat maintenance flows included in this alternative are likely to have short-term effects on angling quality in Glen Canyon. During the early stages of the habitat flow, there would be increased drift of macroinvertebrates and detritus. This would likely stimulate increased trout feeding and thereby improve fishing quality. During the latter days of the habitat maintenance flow period, drift would decline, and continuing high releases might make fishing more difficult than at lower flows. The net effect on angling quality is unknown but likely to be minor due to the short duration of these events.

The daily stage change affecting wading anglers at Lees Ferry would be approximately 2 feet less than under no action. Representative 20-minute stage changes would be approximately 0.24 foot (61 percent less than no action) at Lees Ferry and 0.5 foot (43 percent less than no action) at the dam.

Habitat maintenance and beach/habitat-building flows also would have some effect on the safety of wading anglers. This effect generally would be limited to the transition period when flow is being increased from normal operations to the higher habitat maintenance flows. During this transition, increasing flows might catch unwary anglers in midstream. However, since Lees Ferry is the sole access point for this reach, this potential safety problem could be easily mitigated by notifying anglers in advance of this impending flow change. Once target flows are reached, the risk of angler inundation due to fluctuations would be eliminated. Higher velocity flows would present some increase in risk to wading anglers, but most individuals can recognize this risk and avoid placing themselves in a dangerous situation.

Approximately 75 percent of all **day rafting** parties would be able to negotiate 3-Mile Bar at minimum discharge (5,000 cfs), compared to only a few at 3,000 cfs (U.S. Department of the Interior, 1990). Some boat and motor damage would likely occur.

High, steady habitat maintenance flows would make boating access over 3-Mile Bar easier but might make upstream passage more difficult for boats with smaller engines. Additional caution on the part of boaters might be required to avoid being stranded at mooring sites as the water level recedes.

Discharge levels would improve **white-water boating** trip attributes in terms of guide and trip leader preferences. Fewer white-water boaters (69 percent, or 18 percent less than under no action) would be aware of fluctuating flows because of increased restrictions.

Effects of habitat maintenance flows on white-water boating would be negligible because they would be scheduled before the peak rafting season. Individuals taking trips during the period when habitat maintenance flows begin undoubtedly would notice the transitions between normal operations and maintenance flows. The changes in river stage would be similar to naturally occurring tributary flood events except that they would not include large sediment inflows. Some individuals might perceive high flows without sediment as artificial, which could impact their wilderness experience.

Conversely, habitat maintenance flows would contribute to maintenance of the natural environment, including sandbars and beaches. This might improve the wilderness character of trips for the majority of individuals.

The overall risk of having a white-water accident would be 10 percent less than under the No Action Alternative. The risk index for commercial users would be 7 percent less than under no action; for private users, risk would be 16 percent less. The potential for having to walk around a rapid would be diminished for all trip types. The risk of people going overboard in a rapid would remain during high flow periods.

During habitat maintenance flows, the probability that some passengers may opt or be required to walk around major rapids would be somewhat increased. This could be a problem for handicapped individuals boating during this period. High flows also could increase the risk of white-water boating accidents. However, these flows would be scheduled for only 1 to 2 weeks during low-use periods. For these reasons, the influence of habitat maintenance flows on handicapped access and on white-water boating accidents likely would be negligible.

Average campable area would be greater than the average of 7,720 square feet available under no action. During habitat maintenance flows included in this alternative, changes in stage would require carefully locating camps and mooring sites.

Concerning **lake activities and facilities**, there would likely be improved navigability in the river and at the interface with Lake Mead, but difficulties would remain due to fluctuations in river stage. Sandbars would continue to be exposed during low flow periods, but conditions might be less variable because river velocity would be less variable.

In a year when habitat maintenance flows are scheduled, the level of Lake Powell would be about 1.5 feet above normal from October through March. During the 1 to 2 weeks of habitat maintenance flows in March/April, the level of Lake Powell would fall about 3 feet, resulting in facility adjustment charges of approximately $4,000. Following habitat maintenance flows, the lake would be approximately 1.5 feet below normal. Compared to a year without habitat maintenance flows, lake elevation would gradually increase from March through September.

Modified Low Fluctuating Flow Alternative

This alternative would have the greatest potential (along with interim low fluctuating flows) among the restricted fluctuating flow alternatives to enhance **fishing** by reducing trout stocking in the Glen Canyon reach.

Habitat maintenance flows included in this alternative would likely have short-term effects on angling quality in Glen Canyon. During the early stages of the habitat flow, there would be increased drift of macroinvertebrates and detritus. This would likely stimulate increased trout feeding and thereby improve fishing quality. During the latter days of the habitat maintenance flow period, drift would decline and continuing high releases might make fishing more difficult than at lower flows. The net effect on angling quality is unknown but likely to be minor due to the short duration of these events.

The stage change at Lees Ferry would be approximately 1.5 feet, or 3 feet less than under no action. Representative 20-minute stage changes typically would be in the range of 0.1 foot (83 percent less than no action) at Lees Ferry and 0.3 foot (66 percent less than no action) at the dam. As such, the risk of major impacts to anglers would be reduced.

Habitat maintenance and beach/habitat-building flows also would have some effect on the safety of wading anglers during the transition period when flow is being increased from normal operations to the higher flows. These effects would be the same as described under the Moderate Fluctuating Flow Alternative.

Campable area would have a slight, unquantified improvement over the Moderate Fluctuating Flow Alternative. During most months, the number of available camping areas would be the same as under no action. During days with maximum flows less than 15,000 cfs, the number of available beaches in Glen Canyon would increase by six.

High, steady habitat maintenance flows would make boating access over 3-Mile Bar easier but might make upstream passage more difficult for boats with smaller engines.

White-water boating trips would benefit because the minimum flow and range restriction would reduce effects on mooring/boat management and navigation of rapids. The range of fluctuations would be among those most preferred for both guides/trip leaders and passengers. Effects of habitat maintenance flows on white-water boating would be the same as those described under the Moderate Fluctuating Flow Alternative.

The overall risk of white-water rafters having an accident would be 10 percent less than under no action. The risk index for commercial users would be 7 percent less than under no action, while the index for private users would be 15 percent less. The effects of habitat maintenance flows on handicapped access and on white-water boating accidents likely would be negligible.

Campable area would be slightly improved over the Moderate Fluctuating Flow Alternative. During most months, the number of available camping areas would be the same as under no action. However, during those days when the maximum flow would be less than 15,000 cfs, the number of available beaches in Grand Canyon would increase by 0.2 site per mile in critical reaches and 0.15 site per mile in noncritical reaches. During habitat maintenance flows, changes in stage would require carefully locating camps and mooring sites.

Concerning **lake activities and facilities,** navigability of upper Lake Mead would improve over most other fluctuating flow alternatives, but difficulties would remain since stage would continue to change with the variable flow. Sandbars would continue to be exposed during low flow periods, but conditions would be among the least variable of any fluctuating flow alternative.

In a year when habitat maintenance flows are scheduled, the level of Lake Powell would be about 1.5 feet above normal from October through March. During the 1 to 2 weeks of habitat maintenance flows in March/April, the level of Lake Powell would fall by approximately 3 feet (resulting in facility adjustment charges of approximately $4,000). Following habitat maintenance flows, the lake would be approximately 1.5 feet below normal. Compared to a year without habitat maintenance flows, lake elevation would gradually increase from March through September.

Interim Low Fluctuating Flow Alternative

Except for the influence of habitat maintenance flows, impacts on recreation under the Interim Low Fluctuating Flow Alternative would be the same as under modified low fluctuating flow compared to no action.

Steady Flows

Impacts to recreation under the steady flow alternatives are described in this section. An overview of common impacts is presented first, followed by specific details about individual alternatives.

Releases during low and moderate water years would be comparable to anglers' most preferred **fishing** scenarios. The fishing environment and associated boating activities would be improved the most under these alternatives. As a result, these three alternatives have the highest preference ranking for fishing among alternatives, with the Year-Round Steady Flow Alternative being the most preferred, followed by the Existing Monthly Volume and Seasonally Adjusted Steady Flow Alternatives (see FISH in this chapter).

Under all steady flow alternatives, risk of inundation would be removed for wading anglers.

Although some **day rafting** navigation problems might occur during low discharge months (data suggest that elimination of navigation problems would require 10,000 cfs), the frequency of navigation problems would be extremely low.

All three steady flow alternatives would lessen impacts on **white-water boating** trip attributes. Since there would be virtually no daily fluctuations, the risk of stranding moored boats would be eliminated. On the average, rapids would provide a bigger "roller coaster ride" and would thus be more exciting. There would be a low likelihood of passengers having to walk around rapids. Flows during all months of most years would not impede navigation; as a result, rafting parties would not frequently encounter each other. Except during extreme low flow months, the predictable nature of the flow should result in improvement over no action, reducing effects on itinerary.

As a result of these benefits to white-water recreation, steady flow alternatives have three of the highest four preference rankings among alternatives, with seasonally adjusted steady flows being the most preferred.

Since flows would be steady, the river would seem more like a natural setting under all steady flow alternatives as compared to no action. Approximately 38 percent of white-water boaters would be aware of minor stage changes, such as those between months and for power system emergencies. Because these events are rare, impacts would be considered negligible.

Risk of white-water boating accidents would range from 14 to 21 percent less than under no action, with the Year-Round Steady Flow Alternative being lowest. All alternatives would improve safety relative to no action because of higher minimum flows. None of the alternatives would move large material out of debris flows.

Flows under the steady flow alternatives would be relatively moderate (except in high water volume years) compared to no action. Due to the lack of daily lows and peaks, both the need for handicapped passengers to walk around rapids and the risk of their going overboard would be reduced. Another benefit of these alternatives would be that handicapped individuals would not need to prepare for both low and high flows within one trip.

Steady flow alternatives would improve usable camping area, distribution, and mooring characteristics compared to no action and fluctuating flow alternatives. Benefits would vary by alternative. Sandbars generally would be less dynamic and more stable, with greater potential for vegetation encroachment. Sandbar heights and active widths would be less under the Existing Monthly Volume and Year-Round Steady Flow Alternatives than under any other alternatives. Bar heights under the Seasonally Adjusted Steady Flow Alternative would be maintained due to habitat maintenance flows (table IV-6). The potential for rebuilding and maintaining camping beaches would be greater than under no action and would be similar to those under moderate and modified low fluctuating flows. The loss of sites would continue in some places due to erosion and vegetation development (table IV-10). Vegetation encroachment, and thus potential dependence on vegetation clearing, would be greatest in the long term under the Year-Round and Existing Monthly Volume Steady Flow Alternatives.

Under the Existing Monthly Volume Steady Flow Alternative, the monthly delivery pattern—and therefore the impacts on **lake activities and facilities**—would be the same as under no action. The water release pattern would change under the Seasonally Adjusted and Year-Round Steady Flow Alternatives, but the consequential influences on lake facilities, boating capacity, and shoreline campsite capacity essentially would be the same.

The steady flow alternatives would affect navigability similarly to no action during successive low water years. Daily flows at the river/lake interface would improve navigation because steady flows would not alter the river channel as fluctuating flows would. Conditions would continue to be variable, depending on riverflow and velocity, lake level, and prevailing sediment conditions.

Existing Monthly Volume Steady Flow Alternative

This alternative would benefit **fishing** activities and success. Since trout stranding would be eliminated and potential for recruitment and aquatic productivity would be improved, trout stocking would be reduced.

In the Glen Canyon reach, there would be as many as 18 beaches available for camping and day use in low water years—an increase of 6 (50 percent) more than under no action. However, during peak discharge months, impacts would be the same as under no action.

Steady flows would result in the near elimination of navigation and access problems for **day rafting** parties at 3-Mile Bar.

White-water boating trip attributes would improve to match preferences. Since daily flows would be steady, the river would seem more like a natural setting to river-runners. The overall risk for white-water boaters under this alternative would be approximately 14 percent less than under no action. The risk for commercial users would be 13 percent less than under no action, while the risk for private users would be 15 percent less.

In most years, additional camping area would be available in Grand Canyon compared to no action and the fluctuating flow alternatives. The average area for campsites would be greater than 9,200 square feet, an increase of more than 25 percent. Campable area for large, medium, and small sites would average, respectively, more than 13,980; 4,940; and 2,660 square feet larger than under no action (for 25,000-cfs discharge). During low discharge months, the area would increase for all beaches to 11,740 square feet, or an increase of more than 52 percent compared to no action. Large, medium, and small campsites would increase in average area to 17,660; 6,490; and 3,560 square feet, respectively.

On most days of the year, low water campsites would be usable, increasing distribution of camping beaches to 0.9 site per mile in critical reaches and 1.28 sites per mile in noncritical reaches, an increase of 0.2 (25 percent), and 0.15 (16 percent) site per mile, respectively, compared to no action. During months well above 15,000 cfs, the low water sites would be unusable.

Mooring quality would be good at 92 percent of camping beaches, compared to 64 percent under no action.

Concerning **lake activities and facilities**, navigability of upper Lake Mead would be the same as under no action during successive low water years. The steady nature of daily flows during all years would improve navigation at the river's interface with the lake.

Seasonally Adjusted Steady Flow Alternative

This alternative would improve **fishing** compared to the No Action Alternative, but has the lowest preference ranking for anglers among the steady flow alternatives.

Habitat maintenance flows included in this alternative are likely to have short-term effects on angling quality and the safety of wading anglers in Glen Canyon. These effects would be the same as those described under the Moderate Fluctuating Flow Alternative.

Habitat maintenance flows would make boating access over 3-Mile Bar easier but might make upstream passage more difficult for boats with smaller engines. Additional caution on the part of boaters might be required to avoid being stranded at mooring sites as the water level recedes.

The overall risk index for **white-water boating** would be 16 percent less than under no action. The index for commercial users would be 16 percent less than under no action, while the index for private users would be 17 percent less.

Effects of habitat maintenance flows on white-water boating would be negligible because they would be scheduled before the peak rafting season. Such effects are identical to those described under the Moderate Fluctuating Flow Alternative. The influence of habitat maintenance flows on handicapped access and on white-water boating accidents likely would be negligible.

All steady flow alternatives would increase usable camping area compared to no action and the fluctuating flow alternatives. During habitat maintenance flows included in this alternative, changes in stage would require carefully locating camps and mooring sites.

Concerning **lake activities and facilities**, the seasonal pattern of Lake Powell elevation would be influenced by the change in water releases (a median seasonal difference of 12.7 feet, which is approximately 6 feet less than under no action). However, the resulting effects on lake facilities, safe boating capacity, and shoreline campsite capacity essentially would be the same as under no action.

In a year when habitat maintenance flows are scheduled, the level of Lake Powell would be about 1.5 feet above normal from October through March. During the 1 to 2 weeks of habitat maintenance flows in March/April, the level of Lake Powell would fall by approximately 3 feet (resulting in facility adjustment charges of approximately $4,000). Following habitat maintenance flows, the lake would be approximately 1.5 feet below normal. Compared to a year without habitat maintenance flows, lake elevation would gradually increase from March through September.

Slightly higher deltas would impair navigability in upper Lake Mead.

Year-Round Steady Flow Alternative

Fishing attributes would improve because more reliable minimum flows (11,400 cfs) during the trout spawning season and steady flows throughout the year would result in near elimination of conditions that contribute to stranding and recruitment failure. The trout fishery would be less dependent on stocking than under any other alternative. Year-round steady flows would have the greatest potential for improved spawning, meaning a larger trout population. As a result, this alternative would have the highest preference ranking for anglers.

Since discharge during low water years is likely to be above 12,000 cfs, this alternative would nearly eliminate navigation and access problems for **day rafting** at 3-Mile Bar.

This alternative is the least preferred of the steady flow alternatives for **white-water rafters**, primarily because of the low volume of water that would be released during summer, the peak white-water season.

The overall risk index for white-water boaters under this alternative would be 21 percent less than under no action. The index for commercial users would be 20 percent less than under no action, while the index for private users would be 23 percent less.

Concerning **lake activities and facilities**, the pattern of discharge would result in lake elevations that would differ seasonally (median elevations in some months would be as much as 4 feet different than under no action). The median within-year range for Lake Powell's elevation would be approximately 18 feet for both the Year-Round Steady Flow and the No Action Alternatives.

Compared to other steady flow alternatives, navigation in upper Lake Mead might progressively diminish in quality during the course of the year because of a lack of variability and the possibility of some river sedimentation.

Economics of Recreational Use

Analysis Methods

Statistical models for angling and commercial and private white-water boating were developed by Bishop et al. (1987) and are reported in Boyle et al. (1988). These statistical models describe the relationship among the economic benefits of each recreation activity, the average flow during the month, and the occurrence of fluctuations exceeding 10,000 cfs during the month. For each type of recreation activity, the model calculates net economic benefits per trip and then aggregates benefits over the actual distribution of recreation trips recorded in 1991.

The statistical models predict the same economic benefits for several of the alternatives because some alternatives have identical inputs to the statistical models. For example, both the Interim Low Fluctuating Flow and Existing Monthly

Volume Steady Flow Alternatives have the same average monthly flows. There would be no fluctuations under the Existing Monthly Volume Steady Flow Alternative and no fluctuations over 10,000 cfs under the Interim Low Fluctuating Flow Alternative. Consequently, the statistical models cannot distinguish between these two alternatives. Likewise, the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives all allow daily fluctuations exceeding 10,000 cfs and would have identical average releases. Consequently, the statistical models cannot distinguish among these alternatives.

The 50-year analysis is based on hydrology trace number 60, the same 20-year hydrology trace used in the hydropower impact analysis. The use of this 20-year sequence for analyzing recreation benefits required several steps. First, mean monthly flows were calculated using the monthly release volumes for each alternative. Second, it was determined whether or not fluctuations exceeding 10,000 cfs occurred during the month. The result of these two steps was a 20-year series of data for each alternative. Like the power system analysis, the 20th year was repeated for an additional 30 years to obtain a 50-year data series.

The resulting 50-year data series for each alternative was then used in the previously described models. This procedure yielded a 50-year series of net economic values for each alternative. Using the same methodology as the power economics study, the equivalent annual value of this 50-year series was calculated.[2] Next, the equivalent annual value for each alternative was subtracted from the No Action Alternative's equivalent annual value to obtain the change under each alternative.

The discussion for each alternative focuses primarily on water years 1989 (a low water year), 1987 (a moderate water year), and 1984 (a high water year). Monthly average flows in water year 1984 were extremely high—ranging from about 24,000 cfs to nearly 43,000 cfs. Under the Seasonally Adjusted and Year-Round Steady Flow Alternatives, monthly average flows would range from about 20,000 cfs to over 55,000 cfs. While analysis of the alternatives must include these extremes, water years 1985 and 1986 may represent more typical high flow years. Therefore, analysis of these additional water years has been provided for comparison.

Summary of Impacts on Recreation Economics

Recreation Use. The 1991 level of recreation use is shown in figure III-40 in chapter III. Current NPS regulations restrict the number of trips that can be taken, preventing any increase in white-water boating in Grand Canyon. Thus, it seems unlikely that the number of white-water boating trips will change in response to any of the alternatives. The long waiting list for private permits and the number of commercial passengers who cannot be accommodated due to these restrictions appear to ensure that visitation is unlikely to fall below present levels. For these reasons, white-water boating use is held constant at 1991 levels for this study.

Angling trips may vary with general economic conditions, fishing regulations, and the quality of the fishery. Studies have documented a relationship between angling quality and the number of trips taken. In these studies, angling quality has been measured by the species, number, and size of fish caught as well as by the presence of native fish in the catch. Some alternatives may result in changes in average catch, average fish size, and composition of the fish stock. Presumably, any change in fishery quality would result in a change in the number of trips taken.

Biological models which could predict angling quality are unavailable, and economic models that could predict the number of trips based on angling quality have not been developed. As a result, the magnitude and direction of the biological response to each alternative cannot be

[2] The levelized or equivalent annual value of this series is the amount of money which, if received each year, would yield an amount equal to the present worth of the varying 50-year series of payments. The details of this calculation may be found in Shaner (1979).

assessed now, and it is not possible to predict a resulting change in fishing effort. In the absence of these data, angling recreation is assumed to be at 1991 levels for this study.

Net Economic Value. Release volumes and the magnitude and frequency of fluctuation differ under each alternative. When compared to the No Action Alternative, this variation results in differences in the net economic value of recreation across alternatives.

The estimates of net economic benefit are based on the statistical relationship between flow and recreation, holding all other factors at the time of the study the same, thus creating a "snapshot" in time. Therefore, these benefit estimates do not account for any long-term impacts on the recreation environment that might affect value.

Tables IV-19 through IV-25—included with the discussion of individual alternatives—illustrate the representative annual net economic value of recreation by alternative and type of water release year. These individual tables convey the range of expected recreation economic impact for representative water years but do not reflect the magnitude of the impacts over the long-term (50-year) period of analysis used in this study.

Table IV-18 illustrates the change in equivalent annual value under each alternative compared to no action for the 50-year period. The Seasonally Adjusted Steady Flow Alternative would result in the largest increase in equivalent annual value, $4.76 million, compared to no action. The Maximum Powerplant Capacity and High Fluctuating Flow Alternatives would not change the equivalent annual value of recreational benefits from no action.

Estimates presented in table IV-18 do not capture the long-term impacts of the alternatives on the recreation environment. To the extent that any of

Table IV-18.—Change in equivalent annual value and net present value of recreation for the 50-year planning period[1]

	Change in equivalent annual value compared to no action (1991 nominal $ millions)					Change in net present value (1991 $ million)
Alternative	Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total	Total
No action	0.0	0.0	0.0	0.0	0.0	0.0
Maximum powerplant capacity	0.0	0.0	0.0	0.0	0.0	0.0
High fluctuating flow	0.0	0.0	0.0	0.0	0.0	0.0
Moderate fluctuating flow	0.40	0.10	-0.10	0.0	0.40	4.63
Modified low fluctuating flow	0.90	2.60	0.20	0.04	3.74	43.26
Interim low fluctuating flow	1.00	2.70	0.20	0.04	3.94	45.57
Existing monthly volume steady flow	1.00	2.70	0.20	0.04	3.94	45.57
Seasonally adjusted steady flow	0.80	3.60	0.30	0.06	4.76	55.05
Year-round steady flow	1.00	1.70	0.20	0.03	2.93	23.48

[1] For consistency with power system analysis, the net economic benefits in each year were inflated by the projected gross national product price deflator for that year (Power Resources Committee, 1993) and were discounted using the Federal Discount Rate (8.5 percent). The equivalent annual value was then calculated using the same rate.

the proposed alternatives result in long-term impacts on the recreation environment, the estimates in table IV-18 may overstate or understate the true effects on net economic value.

Regional Economic Activity. Since the number of white-water boating trips is not expected to change and the number of angling trips taken is held constant for this analysis, there is no change in regional economic activity for any of the alternatives. Estimates of local economic activity for the No Action Alternative are reported in chapter III, table III-15. These estimates depend on the number of trips taken by nonresidents and their pattern of expenditures.

Recreation, Economics, and Indian Tribes. A number of commercial and private white-water boating trips launch from Diamond Creek on the Hualapai Reservation. Estimates of the net economic value of white-water boating below Diamond Creek are described in tables IV-19 through IV-25 for representative water years and in table IV-18 for the 50-year analysis.

White-water boating use below Diamond Creek, as measured by the number of trips taken, is expected to increase over time until use reaches capacity limits. The nature and timing of this increase is unknown; however, any change in the number of trips is expected to be unrelated to dam operations. Therefore, white-water boating use is held constant at 1991 use levels, and local economic activity would be identical across all alternatives.

Because no other Native American-owned or operated river-based businesses have been identified, no measurable economic impact would be expected under any of the proposed alternatives.

Unrestricted Fluctuating Flows

Under the unrestricted fluctuating flow alternatives, releases in low water years are characterized by low minimum flows with relatively high peak flows of short duration. As a result, flows fluctuate considerably within the constraints imposed by available storage. Flows generally would be below the optimal recreation level, and fluctuations would affect recreation benefits.

Minimum flows in a moderate release year generally would be higher than in low water years, although flow fluctuations would remain large. In a high water release year, minimum flows are higher than under low and moderate release conditions. In addition, because of the need to release a large volume of water, flow fluctuations are reduced.

No Action Alternative. Net economic benefits to white-water boaters and anglers under the No Action Alternative are presented in table IV-19.

Maximum Powerplant Capacity Alternative. Under this alternative, the net economic benefits of white-water boating and angling are the same as under no action (see table IV-19).

Table IV-19.—Net economic benefits of recreation for representative years under the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives

Type of release year	Annual benefits (1991 nominal $ millions)				
	Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
Low (1989)		5.4	1.1	.104	7.904
Moderate (1987)		6.4	1.2	.122	8.922
High 1 (1984)		12.4	2.0	.230	15.730
High 2 (1985)		11.0	1.7	.204	14.004
High 3 (1986)		10.4	1.6	.186	13.286

Table IV-20.—Net economic benefits of recreation for representative years under the Moderate Fluctuating Flow Alternative

Type of release year	Anglers	Annual benefits (1991 nominal $ millions) Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
Low (1989)		5.2	0.9	.098	7.698
Moderate (1987)		6.4	1.2	.122	8.922
High 1 (1984)		12.4	2.0	.230	15.730
High 2 (1985)		11.0	1.7	.204	14.004
High 3 (1986)		10.4	1.6	.186	13.286

Restricted Fluctuating Flows

The effects of restricted fluctuating flow alternatives on net recreation benefits would vary depending on the type of water year and the actual water volume and pattern of releases during that year. Daily fluctuations over 10,000 cfs would be greatly reduced as the alternatives become progressively more restrictive. For example, under the High Fluctuating Flow Alternative, daily fluctuations over 10,000 cfs would be relatively common, while under the Interim Low Fluctuating Flow Alternative, daily fluctuations exceeding 10,000 cfs would never occur.

High Fluctuating Flow Alternative. There would be no difference between the economic benefits generated under this alternative and those generated under no action in any water year (see table IV-19).

Moderate Fluctuating Flow Alternative. In a typical low water release year, habitat maintenance flows would take place for approximately 10 days in March, resulting in a small decrease between the benefits under the Moderate Fluctuating Flow Alternative and benefits under no action. In moderate and high water release years, habitat maintenance flows would not be scheduled, and benefits would be the same as under no action. The results for commercial white-water boating, private white-water boating, and angling are shown in table IV-20.

Modified Low Fluctuating Flow Alternative. Habitat maintenance flows are a component of the Modified Low Fluctuating Flow Alternative. Including these flows during March changes the volume of water released during the remaining 11 months of the year. In a low water release year,

Table IV-21.—Net economic benefits of recreation for representative years under the Modified Low Fluctuating Flow Alternative

Type of release year	Anglers	Annual benefits (1991 nominal $ millions) Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
Low (1989)		6.3	1.0	.117	9.217
Moderate (1987)		9.1	1.6	.174	12.974
High 1 (1984)		13.3	2.1	.247	16.947
High 2 (1985)		13.6	2.1	.259	17.759
High 3 (1986)		12.9	2.0	.236	16.536

Table IV-22.—Net economic benefits of recreation for representative years under the Interim Low Fluctuating Flow Alternative

Type of release year	Annual benefits (1991 nominal $ millions)				
	Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
Low (1989)	1.8	6.6	1.1	.122	9.622
Moderate (1987)	1.7	9.4	1.7	.174	12.974
High 1 (1984)	1.2	13.4	2.1	.247	16.947
High 2 (1985)	1.4	13.0	2.3	.259	17.759
High 3 (1986)	1.4	12.9	2.0	.236	16.536

the total recreation benefits generated under this alternative would be approximately 17 percent more than under no action.

In a moderate water release year, recreational benefits under this alternative would be approximately 36 percent more than under no action. Because habitat maintenance flows would not take place in moderate release years, there is no difference between modified low and interim low fluctuating flows in these years. Both would increase recreation benefits by approximately 45 percent over no action.

In a high water release year such as 1984, the Modified Low Fluctuating Flow Alternative would produce recreation benefits of approximately 8 percent more than under no action. Because habitat maintenance flows would not take place in high release years such as 1984, 1985, or 1986, there is no difference between modified low and interim low fluctuating flows in these years. Net economic benefits are listed by activity in table IV-21.

Interim Low Fluctuating Flow Alternative. Habitat maintenance flows are not included in the Interim Low Fluctuating Flow Alternative. In a low water release year, the total recreational benefits generated would be approximately 22 percent more than under no action.

In a moderate water release year, recreational benefits of this alternative would be approximately 45 percent more than under no action. In a high water release year such as 1984, recreation

Table IV-23.—Net economic benefits of recreation for representative years under the Existing Monthly Volume Steady Flow Alternative

Type of release year	Annual benefits (1991 nominal $ millions)				
	Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
Low (1989)	1.8	6.6	1.1	.122	9.622
Moderate (1987)	1.7	9.4	1.7	.174	12.975
High 1 (1984)	1.2	13.4	2.1	.248	16.948
High 2 (1985)	1.4	13.8	2.3	.259	17.759
High 3 (1986)	1.4	12.9	2.0	.236	16.536

Table IV-24.—Net economic benefits of recreation for representative years under the Seasonally Adjusted Steady Flow Alternative

Type of release year	Annual benefits (1991 nominal $ millions)				
	Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
Low (1989)	6.7	1.0	.128	9.528	
Moderate (1987)	9.9	1.8	.189	13.489	
High 1 (1984)	11.6	2.0	.233	15.033	
High 2 (1985)	13.1	2.2	.252	16.952	
High 3 (1986)	13.8	2.2	.260	17.760	

benefits would be approximately 8 percent more than under no action. Net economic benefits, by activity, are presented in table IV-22.

Steady Flows

The effect of each steady flow alternative on net recreation benefits would vary depending on the type of water year and actual water volume and pattern of releases during that year. The steady flow alternatives would eliminate daily flow fluctuations exceeding 10,000 cfs. In general, reducing these fluctuations would increase net recreation benefits over no action. However, the Existing Monthly Volume and Seasonally Adjusted Steady Flow Alternatives would decrease mean monthly flows during the season when white-water boating use is high. Depending on the water year, this decrease could offset the benefits gained by eliminating flow fluctuations.

Existing Monthly Volume Steady Flow Alternative. In a low water year, this alternative would generate approximately 22 percent more recreation benefits than no action. In a moderate water release year, the Existing Monthly Volume Steady Flow Alternative would produce a 45-percent increase in recreation benefits compared to no action. In a high water release year such as 1984, recreation benefits would be 8 percent more than no action. The results for angling, commercial white-water boating, and private white-water boating are presented in table IV-23.

Seasonally Adjusted Steady Flow Alternative. In a typical low water year, habitat maintenance flows would be scheduled for approximately 10 days

Table IV-25.—Net economic benefits of recreation for representative years under the Year-Round Steady Flow Alternative

Type of release year	Annual benefits (1991 nominal $ millions)				
	Anglers	Commercial white-water boating	Private white-water boating	White-water boating below Diamond Creek	Total
Low (1989)	5.8	1.0	.110	8.81	
Moderate (1987)	9.9	1.8	.189	13.489	
High 1 (1984)	11.7	2.0	.233	15.133	
High 2 (1985)	13.1	2.2	.251	16.951	
High 3 (1986)	13.8	2.3	.260	17.860	

during March; otherwise, there would be little flow fluctuation within the season. In a low water year like 1989, net recreation benefits would increase by 20 percent over no action.

On the whole, reduced flow fluctuations in a moderate release year would result in increased benefits to white-water boaters and anglers. Compared to no action, this alternative would result in a 51-percent increase in total net benefits.

In high water volume years, the Seasonally Adjusted Steady Flow Alternative would be characterized by relatively high flows during the summer. The flows for 1984 (a representative high flow year) would be higher than the optimal flows for white-water boating and angling, which would decrease net economic benefits by 4 percent from no action.

For comparison, two other high water years—1985 and 1986—were analyzed. The releases in these years may be more typical of high water years. Based on the 1985 flows, seasonally adjusted steady flows would result in a 21-percent increase in total recreation benefits compared to no action. Based on the 1986 flows, seasonally adjusted steady flows would increase 34 percent over no action. Net economic benefits are presented in table IV-24.

Year-Round Steady Flow Alternative. Minimum flows in low and moderate water years would be higher than under no action, and flow fluctuations would be nearly eliminated. Net economic benefits would be increased by 11 percent over no action in a typical low water year. In a moderate water release year, net economic benefits would increase by 51 percent.

In high water years, the Year-Round Steady Flow Alternative would be characterized by relatively high constant flows. In some months, the flows for the 1984 high water release year would be in excess of the optimal flows for white-water boating and angling. Under these conditions, recreation benefits would decrease by 4 percent.

Net economic benefits for all activities under this alternative are shown in table IV-25. Two other high water years—1985 and 1986—also were analyzed. The releases in these years may be more typical of high water years. Under the 1985 water year, net recreation benefits under year-round steady flows would increase 21 percent over no action. Based on the 1986 water year, net recreation benefits would increase 34 percent over no action.

HYDROPOWER

Issue:

How do dam operations affect the ability of Glen Canyon Powerplant to supply HYDROPOWER at the lowest possible cost?

Indicators:

Power operations flexibility
Power marketing resources, costs, and rates

Impacts on power operations relate to changes in how Western Area Power Administration (Western) interacts with and provides electrical services to its Salt Lake City Area Integrated Projects (SLCA/IP) firm power customers and other utilities in the region. Power marketing impacts are based on effects on long-term firm power marketing to about 180 preference customers (Western Area Power Administration, 1992). These preference customers consist of municipal and county utilities, rural electric cooperatives, water districts, irrigation districts, U.S. Government installations, and other nonprofit organizations. In total, approximately 1.7 million end-use customers in Arizona, Colorado, Nevada, New Mexico, Utah, and Wyoming purchase electricity from one of these preference wholesale customers.

Analysis Methods

This impact analysis was based on studies prepared by the GCES Power Resources Committee (Power Resources Committee, 1993) and interviews with operations personnel at

Western's Montrose District Office. Standard electric utility integrated resource planning techniques and the latest available data were used to quantify the impacts of operational changes at Glen Canyon Dam. Computer models used were: CRSS (to simulate future hydrological conditions), the Electric Power Research Institute's Electric Generation Expansion Analysis System and Environmental Defense Fund's Electric Utility Financial and Production Cost Model (to simulate operations of the regional interconnected power system), and Western's Power Repayment Study (to calculate the SLCA/IP firm power rates).

The analysis of the magnitude of power impacts depends on the forecasted demand for electricity, the hydrologic sequence used, the base year used, and the relative resource prices in 1991 (the base year). If actual conditions vary from those assumed in the study, impacts will vary accordingly. The sensitivity of the results presented in this EIS to changes in study assumptions is described in *Power System Impacts of Potential Changes in Glen Canyon Operations* (Phase II and III) (Power Resources Committee, 1993 and 1994).

Long-term firm power marketing impacts were based on the following factors:

- SLCA/IP marketable resource—capacity and energy available for marketing on a long-term basis with an acceptable level of hydrologic risk assumed by Western
- Economic costs—associated with replacing lost capacity at Glen Canyon Dam from a societal or national perspective
- Financial costs—costs and/or benefits associated with replacing lost capacity at Glen Canyon Dam from the perspective of an individual utility or groups of utilities
- Wholesale rates—SLCA/IP combined firm power rate for long-term capacity and energy
- Retail rates—charged by SLCA/IP firm power customers to their residential, commercial, and industrial end users

The terms "economic" and "financial" often are used interchangeably, but here they represent two different concepts. The economic analysis takes a societal or national perspective. It focuses on economic gains or losses within the electrical power industry as a whole. The financial analysis looks at individual utilities or groups of utilities.

The economic analysis assumed two marketing arrangements: hydrology and contract rate of delivery (CROD). The hydrology approach assumed that (1) Western would sell only the capacity and energy generated by SLCA/IP resources resulting from the available hydrology each year, and (2) customers would have to purchase firm capacity and energy elsewhere on an annual basis to meet any additional needs.

The CROD analysis assumed capacity and energy would be marketed according to the post-1989 criteria. That is, Western would contract to provide its customers with long-term firm capacity and energy based on the projected generating capability of SLCA/IP resources with some acceptable level of risk. Under this arrangement, Western would purchase capacity and energy to meet customer contracts in years when SLCA/IP generation wasn't sufficient due to poor hydrology.

In both the hydrology and CROD marketing approaches, it was the customer's responsibility to replace capacity and energy lost as a result of constrained Glen Canyon Dam operations. Another marketing approach that was considered but not studied by the Power Resources Committee was studied by Argonne National Laboratory in preparing the post-1989 power marketing EIS. Under that marketing approach, Western would maintain a high marketing commitment and replace lost capacity on behalf of its SLCA/IP customers. Power system studies performed to support the power marketing EIS confirmed that economic and financial impacts could be reduced considerably by having Western use its expansive transmission system to replace lost capacity.

The financial analysis based on the CROD marketing arrangement examined impacts on utilities, including their costs to build new facilities or buy power elsewhere (utility economic impacts) and costs of transfer payments to buy power elsewhere (interutility transfers). Transfer payments were excluded from the economic analysis because they were considered a redistribution of wealth that would not affect national economic development. However, interutility transfer payments are a real cost to power customers and so were included in the financial analysis.

Estimates of financial impact differ from estimates of economic impact in several respects. First, estimates of financial impact include the fixed and variable costs of generation for both existing and new facilities. Second, financial impact estimates include the costs of insurance, taxes, private capital, and depreciation that are not included in an assessment of economic impact. Third, the estimates of financial impact presented here include both the costs of generation incurred by the producer (if modeled) and the payments made by purchasers. Both costs are aggregated for each transaction between the original producer and the end user. Thus, the estimates of financial impact do not represent an estimate of **net** financial impact within the modeled region. Additional analysis of the financial impact is available in the Power Resources Committee Phase III report (Power Resources Committee, 1994).

Part of the financial analysis used the SLCA/IP firm power rate, replacement resource costs, and administrative costs to estimate resulting retail rates. Revenue requirements (how much a utility must make to stay in business) are affected by:

- Increases in the SLCA/IP combined wholesale rate
- Reductions in Federal firm power allocation
- Increased costs of purchasing replacement power (including transfer payments)

The Power Resources Committee did not specifically study short-term impacts on hydropower. However, impacts would occur immediately following the Record of Decision (ROD), particularly if the ROD does not allow financial exception criteria for 5 to 7 years while long-term replacement resources are being secured. Until contracts between Western and its customers are renegotiated, Western might have to purchase replacement capacity to fulfill its contract obligations. These replacement purchases would increase the cost of service to firm power customers by increasing purchased power costs and/or increasing the SLCA/IP firm power rate.

Long-term impacts (up to 50 years) would include both reduced operational flexibility and less available firm capacity and on-peak firm energy for the region's electrical power market. Long-term impacts to capacity would likely accelerate construction of new gas-fired thermal generation facilities to replace capacity lost at Glen Canyon Dam—construction that otherwise would have been deferred for 5 to 10 years.

Direct impacts would be those that affect day-to-day operations and change the character of the power resource available to Western's customers. Direct impacts also would include those that affect future planning for hydroelectric service, wholesale customers, other interconnected utilities, and power rates. Indirect impacts would affect end-use customers and the goods and services they provide.

Summary of Impacts: Hydropower

The principal values of Glen Canyon Powerplant are its ability to generate electricity without air pollution or using nonrenewable fuel resources and its flexibility to quickly and effectively respond to changes in an interconnected generation and transmission network. Removing the components that make hydropower so flexible and responsive—namely, control of how and when water is released—diminishes those values.

Impacts on power operations and marketing are summarized in table IV-26. Since effects on operations are difficult to quantify in economic and financial terms, they are discussed qualitatively in terms of operational flexibility. The power marketing analysis identifies impacts on long-term firm power marketing due to changes in the amount of marketable resource, economic and financial costs, and wholesale and retail rates.

Initially, endangered fish research flows (likely a seasonally steady pattern) would occur during minimum release years through the Adaptive Management Program. The extent to which steady flows would be permanently incorporated

Table IV-26.—Summary of anticipated impacts on HYDROPOWER during the 50-year period of analysis by alternative

HYDROPOWER	No Action	Maximum Powerplant Capacity	High Fluctuating Flow	Moderate Fluctuating Flow	Modified Low Fluctuating Flow	Interim Low Fluctuating Flow	Existing Monthly Volume Steady Flow	Seasonally Adjusted Steady Flow	Year-Round Steady Flow
Power operations	No effect	Minor/ moderate increase	Minor/ moderate decrease	Moderate decrease	Moderate/ potential to become major decrease	Moderate/ potential to become major decrease	Major decrease	Major decrease	Major decrease
Power marketing									
Marketable resource									
Annual energy (GWh)	6,010	6,010	6,010	6,010	6,018 (+0.1%)	6,010	6,010	6,123 (+1.9%)	6,001 (-0.2%)
Winter capacity (MW)	1,407	1,407	1,383 (-2%)	1,023 (-27.3%)	965 (-31.4%)	1,035 (-26.4%)	840 (-40.3%)	640 (-54.5%)	735 (-47.8%)
Summer capacity (MW)	1,315	1,315	1,272 (-3.3%)	882 (-32.9%)	845 (-35.2%)	876 (-33.4%)	711 (-45.9%)	498 (-62.1%)	615 (-53.2%)
Annual economic costs									
1991 nominal $ million									
Hydrology	0	-1.5	2.1	[1]54.0	[1]15.1	36.3	65.9	[1]88.3	69.7
Contract rate of delivery	0	0	2.5	[1]36.7	[1]44.2	35.6	68.7	[1]123.5	85.7
Present value (1991 $ million)									
Hydrology	0	-17.3	24.3	624.5	174.6	418.7	761.4	1,021.2	805.0
Contract rate of delivery	0	0	28.9	424.5	511.2	411.7	794.6	1,428.4	991.2
Annual financial costs[2]									
1991 nominal $ million	0	0	6.5	77.3	89.1	75.4	124.5	192.4	146.6
Present value (1991 $ million)	0	0	75.2	894.0	1,030.5	872.0	1,439.9	2,225.2	1,695.5
Wholesale rate (1991 mills/kWh)	18.78	18.78	19.38 (+3.2%)	22.82 (+21.5%)	23.16 (+23.3%)	23.18 (+23.4%)	25.22 (+34.3%)	28.20 (+50.2%)	26.78 (+42.6%)
Retail rate (1991 mills/kWh)									
70% of end users	No change	No change	No change to slight decrease	No change to slight decrease	No change to slight decrease	No change to slight decrease	No change to slight decrease	No change to slight decrease	No change to slight decrease
23% of end users	No change	No change	Slight decrease to moderate increase	Slight decrease to moderate increase	Slight decrease to moderate increase	Slight decrease to moderate increase	Slight decrease to moderate increase	Slight de- crease to mod- erate increase	Slight decrease to moderate increase
7% of end users (weighted mean)	64.1	64.1	64.6 (+0.8%)	69.7 (+8.8%)	70.5 (+10.0%)	70.2 (+9.6%)	72.9 (+13.8%)	75.8 (+18.4%)	74.5 (+16.3%)

[1] This estimate was obtained using multiple regression analysis.
[2] These estimates do not represent net financial impact within the modeled area (see section on financial impacts).

would depend on evaluation of the research results. Because these research flows might not occur every year and because results will need to be evaluated, effects of these flows could not be integrated into the summary table of impacts. Endangered fish research flows would have the potential to increase impacts of the selected alternative on power economics up to the level of impacts described under the Seasonally Adjusted Steady Flow Alternative. If such research flows occur only during the initial years of implementation, additional impacts would be minor. However, if steady flows were permanently incorporated in the operating criteria, impacts would be closer to those under the Seasonally Adjusted Steady Flow Alternative.

Power Operations

Impacts on power operations range from minor under the Maximum Powerplant Capacity Alternative to major under the Seasonally Adjusted and Year-Round Steady Flow Alternatives. Many factors go into determining the ultimate impact of an alternative on power operations, and changing one factor may affect all the others. Operational restrictions imposed by all but the No Action and Maximum Powerplant Capacity Alternatives would reduce Western's ability to meet its obligations with maximum efficiency and economy and would reduce Glen Canyon's value as a load following and peaking facility.

Although restrictions on dam operations result in reduced flexibility for power operations, it is important to point out that, given the number of variables involved, impacts can vary from minor to major even within an alternative, depending on the frequency and duration of particular events. An example of how these variable electrical system events can result in different effects is provided in Appendix E, Hydropower.

Power Marketing

All alternatives, except the No Action and Maximum Powerplant Capacity Alternatives, would restrict Glen Canyon Powerplant's flexibility to operate in a way that maximizes the value of electrical generation. Operational restrictions would reduce how much long-term firm power could be marketed. In general, the relative magnitude of impacts to long-term firm power marketing would be:

- Minor to no impact: No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives
- Moderate to potentially major impacts: Moderate Fluctuating, Modified Low Fluctuating, and Interim Low Fluctuating Flow Alternatives
- Major impacts: Existing Monthly Volume, Seasonally Adjusted, and Year-Round Steady Flow Alternatives

SLCA/IP Marketable Resources. Limiting maximum allowable releases would result in less available capacity; restrictions on ramp rates and allowable daily change in flow would further reduce available capacity. Increasing the minimum flows would reduce the value of energy by forcing increased off-peak releases and limiting the ability to make economy energy sales and purchases.

Capacity.—In going from no action to restricted fluctuating and steady flows, operational flexibility would be increasingly limited. The maximum allowable water releases would go down, and the minimum allowable water releases would go up. This pattern would result in a narrower range of flows that would be further restricted by limits on the allowable daily change in flow. Reduced capacity would mean customers would need to generate or purchase additional capacity from other suppliers independently or through Western. Costs of these transactions have been analyzed and are described under individual alternatives.

Also, the limits on allowable up and down ramp rates would determine how fast water releases could get from an existing flow to a desired flow. Figure IV-16 illustrates the drop in seasonal marketable capacity, primarily due to the decreased maximum allowable releases from fluctuating flows to steady flows.

Figures in appendix E show impacts of the alternatives on the cumulative distribution of capacity

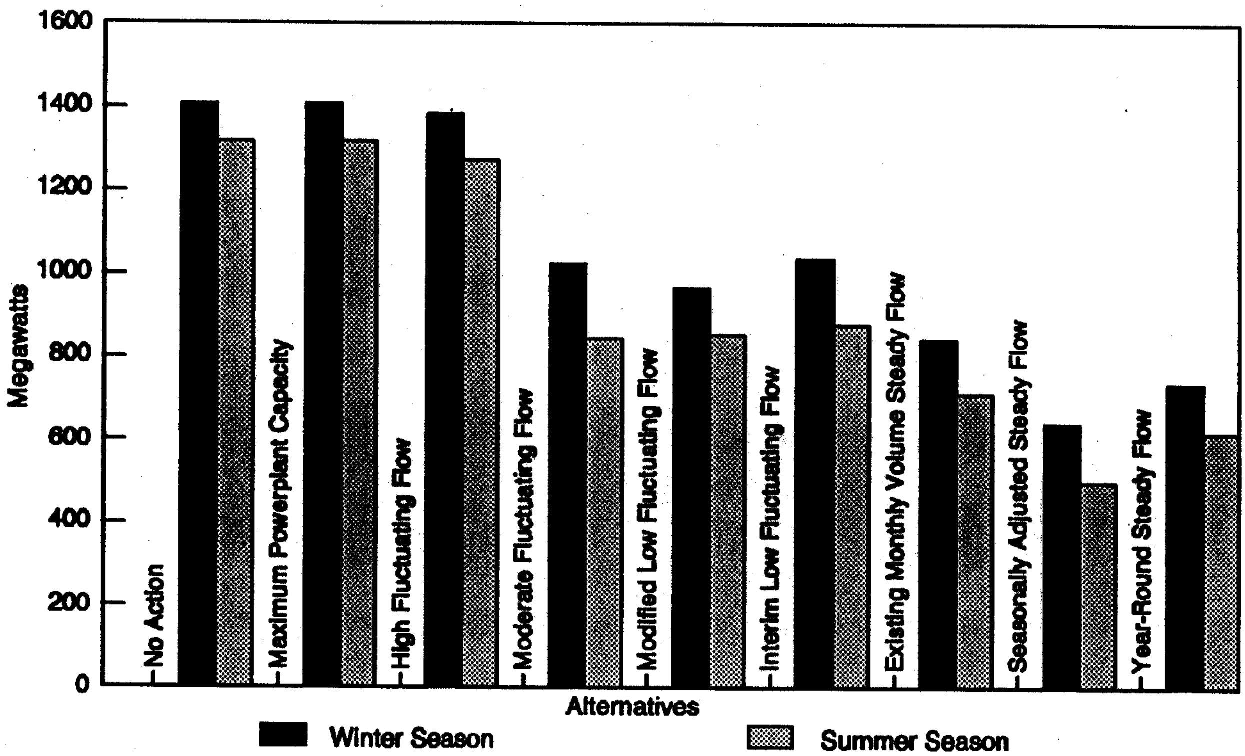


Figure IV-16.—Total SLCA/IP CROD marketable capacity during critical seasons (winter and summer) would vary by alternative.

used to determine SLCA/IP marketable capacity during critical months for the next 20 years.

Energy.—The times when water is released (time of day and season) also would make a difference. Although there would be little or no impact on the quantity of energy produced annually, releasing more water during off-peak hours (nighttime) or during low load months (spring and fall) means:

1. More power would be produced when it is less valuable.

2. Less water would be available for release during on-peak periods (daytime) or during high load months (summer and winter) when power is most valuable.

Other operational restrictions would make it less likely that the maximum allowable releases could be achieved. These restrictions would become even more important during critical summer and winter peak load months.

Economic Costs. Relatively minor short-term economic costs were estimated because firm capacity reductions would be replaced by existing surplus generation. Eventually, the loss of Glen Canyon capacity would mean that new power generation facilities would be required sooner than they would have been under no action. To replace this capacity, Western's larger customers could:

- Purchase replacement capacity from other utilities
- Adjust generation from their own resources

Build additional generation resources

Ask Western to secure replacement resources using their transmission system

Smaller utilities, without significant generating resources, could:

Purchase capacity and energy from auxiliary suppliers

Build their own peaking resources

Ask Western to secure replacement resources using their transmission system

Because of the large amounts of low cost surplus capacity in the regional power market for a considerable portion of the study period, the economic costs of Glen Canyon alternatives were significantly reduced (by over 50 percent) due to cost discounting procedures. Because this discount rate was 8.5 percent, any low values early in the study period significantly weight the results to the low side of the range (e.g., at an 8.5-percent discount rate, $1 promised 10 years in the future has the present worth of only 44 cents). Conversely, large values later in the study period have little impact in weighing the impacts one way or another.

Table IV-26 summarizes the economic costs of each alternative. Figure IV-17 shows the range of costs associated with replacing lost capacity from Glen Canyon Dam.

Financial Costs. The total cost of new generating resources and power purchases for all utilities combined is shown by alternative in table IV-26. The range of financial impacts on utilities is shown in table IV-27. Some utilities would incur higher financial impacts than others, depending on the extent to which they rely on SLCA/IP power.

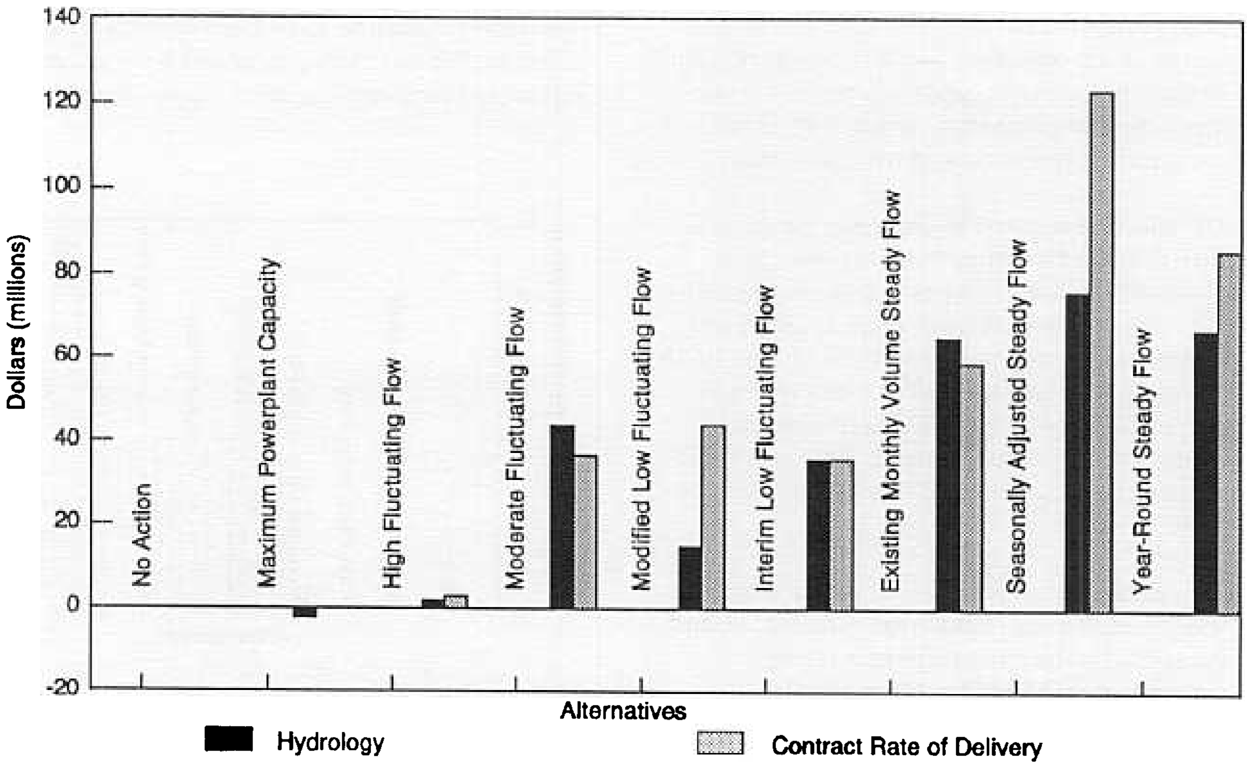


Figure IV-17.—Net annual economic costs would decrease slightly under the Maximum Powerplant Capacity Alternative and increase under all other alternatives compared to no action.

Table IV-27.—Financial impacts on large and small utilities by alternative

Alternative	Large systems			Small systems		
	Low	Median (1991 million $)	High	Low	Median (1991 million $)	
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0.01	0.50	0	0.04	0.74
	0.03	1.57	3.33	0	0.45	8.71
	0.05	1.81	3.75	0	0.50	9.59
	0.03	1.55	3.30	0	0.45	8.65
	1.13	4.58	11.14	0	0.65	12.56
	2.61	8.91	29.15	0	0.88	17.00
	0.98	5.19	15.77	0	0.78	14.76

[1] Does not include impacts of habitat maintenance and beach/habitat-building flows.

Wholesale and Retail Rates. Western primarily markets power at wholesale rates to customers who, in turn, sell at retail rates to their customers.

Wholesale Power Rates.—The SLCA/ IP combined wholesale long-term firm power rate is set at a level consistent with repayment of allocated project costs over a project's useful life or 50 years, whichever is less. Changes in Glen Canyon Dam operations—with possible resulting changes in the marketable resource and in non-firm sales and purchases—would affect allocated costs, project revenues, and wholesale rates.

The effects of reduced hydropower production at Glen Canyon Powerplant on long-term firm power rates—used to repay Federal investment in the Colorado River Storage Project (CRSP) and participating projects—are shown in figure IV-18. These rates assume that, other than purchased power costs, the current SLCA/IP repayment obligation remains unchanged. Firm power rates are used in calculating the impacts on retail power rates.

Retail Power Rates.— Of the 5.6 million end-use customers (residential, commercial, and industrial) in the six-State impact region, approximately 3.9 million (70 percent) do not receive power from the dam. These end users would either experience no increase in power rates or their rates could decline slightly if their utility is able to make additional sales as a result of changes in Glen Canyon Dam operations. The retail rates of the other 1.7 million (30 percent) end users in the region would be affected to varying degrees. Tables IV-26 and IV-28 list the weighted mean retail rate impact for a subset of 0.4 million (7 percent) of these affected end-use customers. Due to a lack of data, time, and resources, the retail rate impact for the remaining 1.3 million (23 percent) large system end-use customers is not now known. Because these large systems are less reliant on Federal hydropower and have greater access to alternative sources of supply, the rate

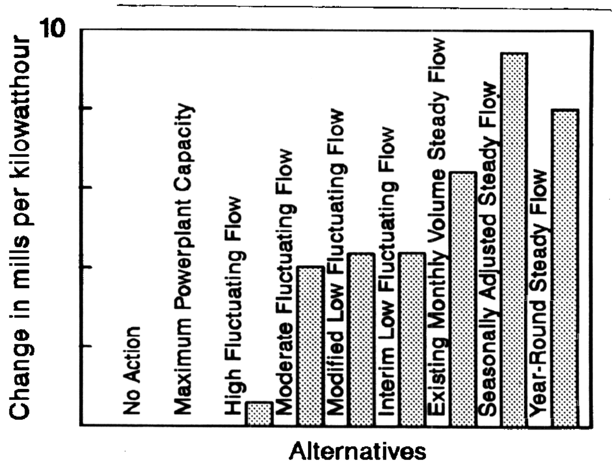


Figure IV-18.—SLCA/IP wholesale rates would increase compared to no action under all alternatives except the Maximum Powerplant Capacity Alternative.

Table IV-28.—Range of estimated small system retail power rates by alternative

Alternative	Retail rate range (mills/kWh) Highest	Customer weighted mean	Lowest
No action	88.1	64.1	30.8
Maximum powerplant capacity	Same as no action	Same as no action	Same as no action
High fluctuating flow	88.5 (+0.4%)	64.6 (+0.8%)	30.9 (+0.4%)
Moderate fluctuating flow	100.4 (+13.9%)	69.7 (+8.8%)	32.0 (+4.0%)
Modified low fluctuating flow	102.3 (+16.1%)	70.5 (+10.0%)	32.2 (+4.5%)
Interim low fluctuating flow	101.2 (+14.8%)	70.2 (+9.6%)	32.1 (+4.3%)
Existing monthly volume steady flow	108.7 (+23.3%)	72.9 (+13.8%)	32.7 (+6.3%)
Seasonally adjusted steady flow	117.0 (+32.8%)	75.8 (+18.4%)	33.3 (+8.3%)
Year-round steady flow	113.2 (+28.4%)	74.5 (+16.3)	33.0 (+7.2%)

impacts on these end users would likely be less than that shown in tables IV-26 and table IV-28.

Retail rate impacts could be relatively significant and vary considerably by utility. Table IV-28 shows the highest, the weighted mean, and the lowest estimated small systems retail rate impacts under each alternative. Such impacts would occur primarily in areas that rely on Federal hydropower: small towns, rural areas, and areas with large amounts of irrigated farmland. Additional analysis of retail rate impacts is in the Power Resources Committee Phase III Report (Power Resources Committee, 1994).

Impacts on small SLCA/IP customer retail rates would depend on:

How much a customer's allocation is affected by a change in the SLCA/IP marketable resource

- The resulting SLCA/IP firm power rate required to meet Federal repayment obligations
- How much a customer relies on SLCA/IP firm power to meet the electric power service needs of its retail customers
- Availability and cost of replacement power

Many customers use revenues from the sale of electricity to supplement other sectors of their government, such as parks and recreation, water systems, city maintenance, etc. A loss of this resource would affect city government budgets and services as revenues diminish.

Regional Economic Activity. The regional economic impacts of changes in electricity rates were examined in Western's power marketing EIS (Western Area Power Administration, 1994). Regional economic impacts were estimated in terms of several key variables: population, employment, output (Gross Regional Product), and disposable income. Impacts were measured in nine subregions, one for each of the metropolitan areas (Albuquerque, Denver, Phoenix, Salt Lake City, Las Vegas, and Casper) and three rural areas (High Plains, Rocky Mountains, Great Basin) in the region.

The alternatives examined in Western's EIS are more extreme, in terms of constraints on the SLCA/IP hydropower resource, than those analyzed in this EIS. The results show that some utilities may experience relatively large rate increases under the alternatives which most closely approximate those examined here. However, these rate increases translate into changes of less than 0.4 percent for any of the variables measured on a regional basis.

These results suggest that implementation of any of the proposed alternatives will not materially affect the regional economy.

Unrestricted Fluctuating Flows

No Action Alternative

Power Operations. Operations under the No Action Alternative would be as flexible as they were prior to implementation of interim flows. There would be an allowable daily range of fluctuation of up to 30,500 cfs and no ramp rate restrictions. The full uprated generating capacity would not be used because the maximum allowable discharge would continue to be administratively limited to 31,500 cfs.

Power Marketing. Impacts would be based on changes in marketable resource, economic and financial costs, and wholesale and retail rates.

SLCA/IP Marketable Resource.—Quantities of SLCA/IP long-term firm capacity and energy under the No Action Alternative are summarized in table IV-26.

Economic Costs.—Studies concluded that, for the next decade (1991-2001), electrical load growth would be met by purchasing existing surplus capacity from interconnected utilities within the regional power market. Energy conservation would prolong this surplus. Aside from the addition of two small combustion turbines in 1996 and 1997 to replace older systems to meet capacity reserve requirements, no significant capacity additions would be made until the year 2001. The total long-term capacity added under the No Action Alternative would be 2,089 megawatts (MW) for the 20-year planning period. The significant capacity additions would include:

- 600 MW of coal-fired generation
- 350 MW of purchased power (150 MW of which are short-term purchases excluded from the total)
- 530 MW of combustion turbines
- 200 MW of pumped storage
- 560 MW from energy conservation

Financial Costs.—The utility economic analysis focused on how and where economic impacts would be distributed. This analysis includes the same procedures performed for the economic analysis except that it describes impacts on small and large utilities and includes transfer payments. As explained in the economic analysis, 2,089 MW would be added to the regional power market by the year 2011. This added capacity would be due to planned expansion by individual utilities to meet projected load growth.

A breakdown of impacts to large and small utilities is shown in table IV-27. Again, a total production cost for the No Action Alternative was not available, so the other alternatives were compared to a zero baseline for no action.

Wholesale and Retail Rates.—The current firm power rate (under interim flows) is 16.72 mills per kilowatthour (kWh) compared to 18.78 mills/kWh for the No Action Alternative. The ratesetting year for this hypothetical rate is fiscal year 1993, chosen because it was the year when estimated revenues most closely matched estimated costs. The minimum rate required to ensure project repayment would include expenses for project operation and maintenance and for extensive environmental studies.

Table IV-26 shows the expected retail rates under each alternative for small systems within the SLCA/IP. Estimates of minimum and maximum retail rates are shown in table IV-28.

Maximum Powerplant Capacity Alternative

The uprating and rewinding of Glen Canyon Powerplant units (completed in 1987) has improved efficiency. **Power operations** under the Maximum Powerplant Capacity Alternative would be the same as those under the No Action Alternative, except that the full uprated capacity of the powerplant (33,200 cfs) would be available for use.

Maximum powerplant capacity is achieved by releasing 33,200 cfs, which would occur only when Lake Powell is at elevation 3641 feet or higher. CRSS model projections show Lake Powell would be at that elevation over 60 percent of the time during the next 50 years. At times during those years, Glen Canyon Powerplant could generate up to 56 MW more capacity than under no action. Additional capacity and energy would then be available for regulation, emergencies, reserve, and the economy energy program.

Impacts on all aspects of long-term firm **power marketing** would be the same as under no action.

Restricted Fluctuating Flows

Power Operations

The following discussion is a general description of impacts to operational flexibility for all restricted fluctuating flow alternatives.

Scheduling. Under restricted fluctuating flows, other variables (water levels, unit outages, and special water releases) would affect the amount of energy that needs to be prescheduled and the price paid for that energy. Extended low-volume releases might result in the need for Western to purchase firm capacity with energy to ensure its customers of a dependable source.

Assuming appropriate market conditions and full unit availability, the criteria limiting use of Glen Canyon Powerplant to provide economy energy would be restrictions on ramping and daily fluctuations. Also, the higher the minimum release, the more limited the flexibility.

Each restricted fluctuating flow alternative has higher minimum flows during off-peak hours compared to the No Action or Maximum Powerplant Capacity Alternatives; therefore, forced economy, off-peak energy sales would be necessary. In other words, when more energy is generated than required to meet load during off-peak hours, Western might be forced to lower its price. Western's customers would then be charged more for the power purchased during on-peak hours in order to generate the revenue necessary to meet repayment requirements.

The additional hydroelectric generation at off-peak times means fossil fuel plants could lose money as a result of losing sales to Western's cheaper energy. Western also would not be purchasing energy from the fossil fuel plants during off-peak times, as it would under no action operations. However, since the fossil fuel plants would have to generate more on-peak energy when Glen Canyon Powerplant is less able to respond to demand, sales to other utilities would be expected to increase.

Compared to operations under no action, less on-peak energy would be generated at Glen Canyon Powerplant. Consequently, there would be little, if any, on-peak energy that could be sold to or exchanged with other utilities at prices lower than generation costs at alternative thermal units.

Impacts on scheduling generation, purchases, water patterns, and other elements depend on the allowable daily change in flows and ramp rates. The more operations are restricted, the more significant the impact. Effects on scheduling would occur hourly and result in increased costs. Under restricted fluctuating flows, Western would have limited options in responding to energy shortages when loads become higher than generation. Power dispatchers would have decreased flexibility to take advantage of market conditions in purchasing or selling capacity and energy.

Discussion of changes expected under restricted fluctuating flow alternatives is based on changes occurring under interim flows (same as the Interim Low Fluctuating Flow Alternative). These changes would include:

1. System efficiency would be reduced.

2. Customers would have to do their own load forecasting, and many small utilities do not have the expertise to make accurate predictions. Inaccurate predictions could be a financial risk for these customers since some suppliers charge much higher rates to provide generation over and above the forecasted amount.

3. Customers would have to follow load with their own units or with purchases from alternate suppliers. The availability of alternate suppliers is limited at times and frequently costs more.

Western lost about 400 MW of capacity due to the restrictions imposed by interim flows. This figure represents about 21 percent of the total SLCA/IP maximum operating capacity. To date, under interim flows, the tendency for system component loads to peak at different times (system diversity[3]) has saved Western from having to purchase capacity. Western currently averages about 10- to 15-percent available capacity above peak needs due to system diversity. Prior to implementation of interim flows, Western averaged about 30-percent available capacity above peak needs.

Under the High Fluctuating Flow Alternative, system efficiency would be reduced compared to no action, but not as much as under Moderate Fluctuating Flows, due to the greater allowable daily change in flows, greater allowable ramp rates, and lower allowable minimum discharge. Under the Moderate Fluctuating Flow Alternative, the availability of Glen Canyon Powerplant to provide customer services and contribute to system efficiency would be reduced compared to that under no action. Customer services and operational efficiency would not be reduced as much under interim low fluctuating flows, due to the greater system flexibility, including allowable daily change in flows, greater allowable ramp rates, higher allowable maximum discharge, and lower allowable minimum discharge.

Load Following. Daily fluctuation limits would restrict use of Glen Canyon Powerplant to respond to changing firm load requirements. For example, a 5,000-cfs change per day allows for only a 190-MW load following capability, and firm load requirements change more than this. Western would find it necessary to make hourly purchases of on-peak, nonfirm energy against the restricted capacity at Glen Canyon Dam to meet firm contract commitments.

The daily fluctuation limit also is tied very closely to up and down ramp rates and the maximum flow limits. For example, under the Interim Low Fluctuating Flow Alternative, the maximum release is 20,000 cfs and the maximum allowable daily change in flows is 8,000 cfs; maximum allowable ramp rates are 2,500 cfs up and 1,500 cfs down. Given those restrictions, if the minimum allowable discharge of 5,000 cfs were released during the night, then water releases could increase to no more than 13,000 cfs during that day. The fastest that releases could increase from 5,000 cfs to 13,000 cfs would be 4 hours (2,500 cfs/hour). Releases could be returned to 5,000 cfs in 6 hours (1,500 cfs/hour)—a major change compared to no action, where flow change capability is plus or minus 33,200 cfs in less than 10 minutes.

When water releases are constrained, operable capacity would be reclassified as inoperable capacity, and the contracted amount might have to be changed. Given restrictions under interim operations, total operable capacity from Glen

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[3] System diversity is the difference between actual firm load requirements (hourly) and total firm contractual commitments and control area regulation requirements. Diversity changes hourly depending on contractor scheduling practices. Western must maintain operating reserves equivalent to its firm contractual commitments and regulation requirements. Western could not reduce capacity in relation to diversity without affecting responsiveness and the ability to conform to the North American Electric Reliability Council guidelines.

Canyon Powerplant and the other CRSP units could be less than that required to simultaneously satisfy firm load requirements and maintain an acceptable amount of capacity in reserve to cover emergencies. Western would have to acquire a substitute uninterruptible source, at higher expense, to replace this lost capacity.

Regulation and Control. As a load control area operator, Western's function is to ensure that each area utility or group of utilities generates the exact amount of power to meet its load and export responsibilities without relying on the resources of others.

System control would be unaffected if there were no stability, frequency, or voltage problems anywhere in the system; however, impacts ranging from minor to major could result if other CRSP units had problems. Problems with system regulation occur frequently, while problems with system control are fairly infrequent. The degree of impact to system regulation and control would depend on the nature of the problem, what period of the day the problem occurred, and how much of Glen Canyon's daily release fluctuation limit had already been used.

For example, if Flaming Gorge Powerplant were being used for system regulation and one of its generating units went down, one of the other resources within the CRSP would be used, most likely Glen Canyon Powerplant. If Glen Canyon had already used its maximum allowable fluctuations for the day, and the Flaming Gorge unit went down during a peak hour, Western would be forced to use one of the Aspinall units or go outside its CRSP resources to cover load requirements. Uninterrupted service is the purpose of an interconnected utility system. However, options are sometimes limited—and the fewer options available, the more significant the impact would be in terms of cost to find and acquire the energy or capacity needed.

Under all restricted fluctuating flow alternatives, less Glen Canyon capacity would be available for regulation service, so some regulation would have to be provided by another CRSP powerplant. If another CRSP powerplant were not available, Western would not be able to meet Western Systems Coordinating Council criteria. Western Area Upper Colorado (WAUC) members would then have to use other, less responsive and more expensive thermal resources. Compared to operations under the No Action Alternative, the High Fluctuating Flow Alternative would reduce capacity by a small percentage. The Moderate, Modified Low, and Interim Low Fluctuating Flow Alternatives would reduce capacity substantially.

Emergencies and Outage Assistance. Restrictions on ramping and maximum allowable releases would result in reduced emergency assistance service. A reduction in this service would result in increased costs and inconvenience, as customers turn to more costly and less reliable thermal sources.

Western would be able to respond only to extensive control area emergencies. Such emergencies usually develop from smaller, localized events and could be kept short term and manageable by using hydropower. Without access to a hydropower source for emergency assistance, a utility may have to search for help from a less responsive thermal unit. Meanwhile, the electrical emergency could progress from local to areawide, forcing the use of Glen Canyon Powerplant to correct the situation.

Financial impacts of reduced emergency assistance from Glen Canyon can be seen in comparisons of 1991 interim flows and 1988 flows, shown in table IV-29. This table is meant to show comparable impacts of the No Action Alternative (1988 flows) to conditions under interim flows.

Under the interim flows of 1991, less emergency energy was available compared to the no action conditions in 1988 and, therefore, less revenue was realized. Utilities that normally would have used hydropower for assistance were forced to seek out less responsive, more expensive sources. Additional expenses varied and were determined by market conditions at the time. The cost impacts for emergency assistance would be expected to be less under the High and Moderate Fluctuating Flow Alternatives because operational limits would be less restrictive and the service

Table IV-29.—Comparison of emergency assistance under no action and interim operations

1988 (no action)	1991 (interim flows)
31,757 MWh provided (returned at 1.5 x 31,757 MWh or a net gain of 15,879 MWh)	8,134 MWh provided (returned at 1.5 x 8,134 MWh or a net gain of 4,067 MWh)
349 MW/hour peak delivery (valued at 20 mills/kWh or a net gain of $317,570)	161 MW/hour peak delivery (valued at 20 mills/kWh or a net gain of $81,340)

could be offered more frequently. It is important to note that wholesale rates would vary among the alternatives to produce the same revenue over the long term for project repayment purposes.

The relative frequency of Inland Power Pool (IPP) emergency assistance requests during the 2 years was the same, but the amount of assistance provided by Western decreased considerably. In 1991, Western provided only up to its reserve requirement, except in cases where a major systemwide or loss of load emergency occurred. Under all restricted fluctuating flow alternatives, Western would provide only up to its share of IPP spinning reserve requirements.

Under all restricted fluctuating flows, the ability to provide scheduled outage assistance could be reduced to zero, resulting in increased costs to other members of the IPP. Financial impacts of reduced scheduled outage assistance to IPP members from CRSP facilities for the 1988 flow year compared to the 1991 flow year are shown in table IV-30.

Transmission System. Restricted fluctuating flows would result in scheduling problems across transmission lines. The greater the restrictions at Glen Canyon, the greater the potential for problems. Transmission scheduling problems arise from physical limitations of the Glen Canyon Dam and Western Colorado transmission systems. If problems occurred—such as heavy power flows, out-of-service transmission lines, or loss of other generating resources—Western would not be able to accommodate the subsequent system schedule changes now usually resolved by rescheduling generation at Glen Canyon Dam and another interconnected powerplant.

Western's ability to wheel firm and nonfirm transmission service would be less. The value of wheeling depends on how much the service is needed, whether Western is situated appropriately within the grid, and the market conditions at the time. Under restricted fluctuating flows, the Glen Canyon-Pinnacle Peak transmission line uprate would be an underutilized investment.

Discussion of impacts to physical transmission components assumes Western would not have financial exception criteria for unscheduled transmission operations and maintenance work. The restricted fluctuating flow alternatives would limit the capability to quickly and efficiently alter the generation pattern of the interconnected

Table IV-30.—Comparison of scheduled outage assistance under no action and interim flows

1988 (no action)	1991 (interim flows)
9,334 MW of capacity provided a net gain of $111,125 (100 MW peak amount sold)	No scheduled outage assistance provided
14,001 MWh energy returned for a net gain of 4,667 MWh (valued at 20 mills/kWh for a net gain of $93,340)	No revenue

system, particularly for short-notice outages and unforeseen heavy loading of the Western Colorado or Glen Canyon transmission system. The degree of impact would depend on when the problem occurred.

Should the Shiprock-Kayenta transmission line go out of service while either or both Glen Canyon and Aspinall Unit Powerplants are restricted, Western would be forced to seek outside assistance through an exchange with the Salt River Project (SRP) or by purchasing additional energy.

Depending on generation capability at Glen Canyon and electricity demands, a full hydrothermal exchange might not be possible. Therefore, SRP would not be able to fully use the power generated at Four Corners, Craig, and Hayden Powerplants to meet its loads. Limitations also would be placed on wheeling SRP power across Western's transmission lines. SRP would incur added expense in purchasing other power generation.

Power Marketing

Since impacts on power marketing would vary, they are discussed under each alternative.

High Fluctuating Flow Alternative

The marketable resource available for firm **power marketing** under the High Fluctuating Flow Alternative would decrease by 24 MW of capacity in winter and 43 MW in summer compared to no action. The amount of annual energy would be the same as under no action; however, restrictions would shift generation from on-peak to off-peak hours, resulting in a minor impact in energy value.

This alternative would result in minor economic costs compared to no action. Economic costs would increase by $2.1 million to $2.5 million per year over no action. In addition to the capacity added under no action, an additional 3 MW of energy conservation would be added.

Financial costs to utilities would increase by $6.5 million over no action. A comparison of costs to large and small utility systems also is presented in table IV-27.

The wholesale firm power rate would increase by 3.2 percent, and the weighted mean small system retail rate would increase by 0.8 percent compared to no action (see table IV-28).

Moderate Fluctuating Flow Alternative

The marketable resource available for firm **power marketing** under the Moderate Fluctuating Flow Alternative would decrease by 384 MW of capacity in winter and 433 MW in summer compared to the No Action Alternative. The annual quantity of energy would be the same; however, a shift in generation from on-peak to off-peak would have a moderate to potentially major impact on energy value.

The Moderate Fluctuating Flow Alternative would result in moderate to potentially major economic costs compared to no action. Significant amounts of existing surplus capacity compounded by the addition of energy conservation during this period would prolong the surplus capacity market condition, but not for as long as under the three previous alternatives. Economic costs would increase by $36.7 million to $54 million per year over no action. In addition to power resources added under no action, the following would be added under moderate fluctuating flows for the 20-year planning period: 50 MW of short-term purchased power, 50 MW of pumped storage, and 3 MW of energy conservation.[4]

Financial costs to utilities would increase by $77.3 million per year. Differences in costs to large and small utility systems relative to no action are summarized in table IV-27.

The wholesale firm power rate would increase by 21.5 percent, and the weighted mean small system retail rate would increase by 8.8 percent compared to no action.

[4] This expansion plan does not reflect the effects of habitat maintenance and beach/habitat-building flows, if any.

Modified Low Fluctuating Flow Alternative

The marketable resource available for firm **power marketing** under this alternative would be reduced by 442 MW of capacity in winter and 463 MW in summer compared to no action. The annual quantity of energy would be the same as under no action; however, a shift in generation from on-peak to off-peak would have a moderate to potentially major impact on energy value.

Under the Modified Low Fluctuating Flow Alternative, moderate to potentially major economic costs would result. Economic costs would increase by $15.1 to $44.2 million per year. Again, surplus capacity would exist and energy conservation would extend the surplus. Power resources added would be essentially the same as under moderate fluctuating flows.

Financial costs to utilities would increase by $89.1 million per year. Differences in costs to large and small utility systems relative to no action are summarized in table IV-27.

The wholesale firm power rate under modified low fluctuating flows would increase by 23.3 percent, and the weighted mean small system retail rate would increase by 10.0 percent compared to the No Action Alternative.

Additional analysis of the Modified Low Fluctuating Flow Alternative was completed for this final EIS. This analysis is described more completely in the Power Resource Committee Phase III Report (1994). The analysis more correctly accounts for the shifting of generation from on- to off-peak and for regional emissions, uses different assumptions about the cost of replacement power purchased by small systems (economic analyses only), and corrects some input data and escalation rates. Estimates for the Modified Low Fluctuating Flow Alternative are listed below.

	Annual economic cost (1991 nominal $ millions)
CROD	34.8 (21% lower than Phase II)
Hydrology	25.0 (66% higher than Phase II)
Annual financial costs	91.7 (3% higher than Phase II)

Phase III results for the other alternatives presumably would be similar to the results for this alternative. As shown in table IV-26, the relative ranking of the alternatives, in terms of cost, differs between the CROD and hydrology modeling approaches. There is at least some evidence that this difference may be more pronounced in the Phase III results. Time and resources were unavailable to complete a Phase III analysis for the other eight alternatives, which precludes comparing all of the alternatives on an equivalent basis.

Interim Low Fluctuating Flow Alternative

Under this alternative, the marketable resource available for firm **power marketing** would decrease by 372 MW of capacity in winter and 439 MW in summer compared to the No Action Alternative. The annual quantity of energy would be the same as under no action; however, a shift in generation from on-peak to off-peak would have a moderate to potentially major impact on the value of the energy.

Moderate to potentially major economic costs would result under interim low fluctuating flows compared to no action. Economic costs would increase by $35.6 to $36.3 million per year. Power resources added would be essentially identical to those added for the Moderate and Modified Low Fluctuating Flow Alternatives.

Under this alternative, financial costs to utilities would increase by $75.4 million per year compared to no action. Differences in costs to large and small utility systems are summarized in table IV-27.

The wholesale firm power rate would increase by 23.4 percent, and the weighted mean small system retail rate would increase by 9.6 percent compared to no action.

Steady Flows

Power Operations

Under the steady flow alternatives, impacts on power operations usually would be much greater than impacts under the restricted fluctuating flow alternatives. Additional impacts to hydropower operations under the steady flow alternatives are described below.

Scheduling. Major impacts to scheduling could occur since plus or minus 1,000 cfs would be the maximum allowable change per 24 hours under the steady flow alternatives. Purchases and sales of firm capacity would result in major cost increases because Western would not be able to buy or sell during economical periods.

Load Following. Western would not be able to provide load following under steady flows due to restrictions on daily fluctuations, up and down ramp rates, and the cap on maximum flows.

Regulation and Control. Impacts on regulation service and control under steady flows would be considered major because releases would not fluctuate.

Emergencies and Outage Assistance. Steady flows would be expected to result in a loss of this service. Under steady flows, Western could provide only its share of IPP capacity reserve requirements and operating reserves equivalent to the WAUC peak load for a minimum of 4 hours per day, except for extensive emergencies. Scheduled outage assistance would be reduced to no more than plus or minus 35 MW (1,000 cfs).

Transmission System. A major loss of operating flexibility would prevent Western from accommodating schedule changes. Impacts on the transmission system actual would be major compared to no action and restricted fluctuating flows.

Power Marketing

Since impacts on power marketing would vary, they are described under each alternative.

Existing Monthly Volume Steady Flow Alternative

Under the Existing Monthly Volume Steady Flow Alternative, the marketable resource available for firm **power marketing** would decrease by 567 MW of capacity in winter and 604 MW in summer compared to the No Action Alternative. The annual quantity of energy would be the same as under no action; however, a shift in generation from on-peak to off-peak would result in a major decrease in energy value.

Major economic costs would result under the Existing Monthly Volume Steady Flow Alternative compared to no action. Economic costs would increase by $65.9 million to $68.7 million per year. The existing system surplus would mean no capacity would be added immediately. Total added capacity would be 2,281 MW for the 20-year planning period—more than 400 MW greater than under the most restrictive fluctuating flow alternative. Power resource additions beyond those under no action would include: 300 MW of short-term purchased power, 142 MW of combustion turbines, and 50 MW of pumped storage (see footnote on page 311).

Financial costs to utilities under this alternative would increase by $124.5 million a year. Differences in costs to large and small utility systems relative to no action are summarized in table IV-27.

The wholesale firm power rate under the Existing Monthly Volume Steady Flow Alternative would increase by 34.3 percent, and the weighted mean small systems retail rate would increase by 13.8 percent compared to the No Action Alternative.

Seasonally Adjusted Steady Flow Alternative

Under the Seasonally Adjusted Steady Flow Alternative, the marketable resource available for firm **power marketing** would decrease by 767 MW of capacity in winter and 817 MW in summer compared to the No Action Alternative. The annual quantity of energy would be nearly the same as under no action; however, a shift in generation from on-peak to off-peak would have a major impact on energy value.

Major economic costs would result under this alternative compared to no action. Economic costs would increase by $88.3 million to $123.5 million per year. Power resources added would require significantly larger quantities of each resource than those added under no action, any of the fluctuating flow alternatives, or any of the other steady flow alternatives. Again, existing surplus capacity and energy conservation would mean new capacity would not be added immediately. However, the large capacity loss would require capacity additions sooner and of greater magnitude. Total capacity added under the Seasonally Adjusted Steady Flow Alternative would be 2,406 MW for the 20-year planning period. Significant capacity increases beyond those under no action would include: 450 additional MW of short-term purchased power, 250 MW of combustion turbines, 50 MW of pumped storage, and 17 MW of energy conservation (see footnote on page 311).

Financial costs to utilities under this alternative would increase by $192.4 million per year compared to no action. Differences in costs to large and small utility systems relative to no action are summarized in table IV-27.

Under seasonally adjusted steady flows, the wholesale firm power rate would increase by 50.2 percent, and the weighted mean small system retail rate would increase by 18.4 percent compared to no action.

Year-Round Steady Flow Alternative

Under the Year-Round Steady Flow Alternative, the marketable resource available for firm **power marketing** would decrease by 672 MW of capacity in winter and 700 MW in summer compared to the No Action Alternative. The annual quantity of energy would be nearly the same as under no action; however, a shift in generation from on-peak to off-peak would result in a major decrease in the value of energy.

Major economic costs would result under this alternative, increasing by $69.7 million to $85.7 million per year. Resource options added for the Year-Round Steady Flow Alternative would be significantly larger than under no action or any of the fluctuating flow alternatives. Again, surplus capacity and energy conservation would mean replacement capacity would not be added immediately. However, the large capacity loss would require capacity additions sooner and of greater magnitude. The total capacity added would be 2,318 MW for the 20-year planning period. Specific capacity additions beyond those under no action would include: 280 MW of short-term purchased power, 251 MW of combustion turbines, 25 MW of pumped storage, 10 MW from wind generators, and 17 MW from energy conservation (see footnote on page 311).

Financial costs to utilities under this alternative would increase by $146.6 million per year. Differences in costs to large and small utility systems compared to no action are summarized in table IV-27.

Under the Year-Round Steady Flow Alternative, the wholesale firm power rate would be increased by 42.6 percent, and the weighted mean small system retail rate would increase by 16.3 percent compared to no action.

NON-USE VALUE

Focus group results indicated that non-use value for operational changes at Glen Canyon Dam may be estimable. As reported in chapter III, the cooperating agencies decided to continue the investigation in two phases: a pilot test research phase and a full-scale study.

Pilot Test

The pilot test phase:

- Evaluated survey instrument performance
- Evaluated the sensitivity of non-use values to changes in affected resources
- Tested hypothesis that non-use value in the CRSP market area differs from that in the Nation as a whole
- Explored interaction of non-use value and price impacts on rural households

A series of discussions were held with sediment experts, fisheries biologists, and other researchers to develop neutral, technically defensible survey instruments. Using an iterative process, impact scenarios for use in the surveys were constructed and cross-checked by researchers.

A focus group in New Mexico and two subsequent focus groups in Arizona explored whether individuals held any value beyond a use value for the hydropower resource. No non-use value for the hydropower resource *per se* was evident. However, participants in these focus groups clearly empathized with particular populations, such as small farmers and rural residents, whose lifestyles might be affected by the price impacts associated with the loss of peaking capability at Glen Canyon Dam. Therefore, descriptions of residential price impacts and impacts on farmers were developed and included in the pilot test survey instruments.

The survey form was approved in January 1994 and mailed to 1,750 households drawn at random from a national sample and to 500 households drawn at random from the CRSP marketing area. Response rates for the pilot test were 76 percent for the marketing area survey and 60 percent for the national survey. Non-use value was found to be significantly different from zero for the impacted resources. Estimates of non-use value in the national sample were significantly larger than those in the market area and increased across the alternatives (Moderate Fluctuating, Interim Low Fluctuating, and Seasonally Adjusted Steady Flow Alternatives) in both samples. However, these increases in non-use value were not always statistically significant. Results of the pilot test are reported in Welsh et al. (1994).

Peer reviewers of the pilot test suggested some methodology improvements and additional analyses and agreed that a full-scale investigation was both feasible and warranted. These findings are further described in Welsh et al. (1994). The results of the pilot test and peer review findings were presented to the cooperating agencies, and the decision was made to proceed with the full-scale non-use value study in June 1994.

Full-Scale Study

The surveys used in the pilot test phase were revised for use in the full-scale investigation based on pilot test results, peer review committee suggestions, and non-use value committee comments. Further discussions were held with sediment experts, fisheries biologists, and other researchers to ensure that the survey instruments reflected the most recent scientific information. The most recent estimates of price impact on residential power users and farmers were also incorporated. Finally, the surveys were cross-checked by researchers, reviewed by members of the non-use value committee, and approved by the Office of Management and Budget.

The institutional framework and underlying theory employed in the full-scale non-use value study are discussed in Harpman, Welsh, and Bishop (1995). A detailed description of the methodology can be found in Bishop et al. (1991) and in Bishop and Welsh (1992a). Additional reading on non-use value and benefit cost analysis is found in Bishop and Welsh (1992b).

Administration of the full-scale survey began in October 1994 and should be completed in January 1995. The full-scale survey was administered to a random sample of 2,550 households in the CRSP marketing area and 3,450 households randomly selected from a national sample. This final EIS was completed prior to the completion of the full-scale non-use value study. Findings of the full-scale non-use value survey will be reported in a separate GCES report.

Possible Results of Non-Use Value Study

Pilot test sample sizes were too small to allow for statistically reliable estimation of non-use value for each of the alternatives. While it is now impossible to predict the numerical magnitude of non-use value for each alternative, it is possible to characterize qualitatively the likely results of the full-scale study.

Since non-users were most concerned about impacts to vegetation and associated wildlife, native fish, Native Americans, and archeological sites, alternatives that benefit these resources are likely to have higher non-use value. Pilot-test results indicate that estimates of non-use value obtained in the full-scale study may range from tens to hundreds of millions of dollars annually.

CUMULATIVE IMPACTS

This section presents an analysis of impacts on the environment which result from incremental impacts of the action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency (Federal or non-Federal) or person undertakes such actions.

Since there are no anticipated construction projects on the Colorado River between Lakes Powell and Mead, there are no cumulative impacts in the immediate area.

Endangered fish research flows (likely a seasonally steady release pattern) would be implemented and evaluated through the Adaptive Management Program. The extent to which these steady flows would be permanently incorporated would depend on evaluation of the research results. Because the research flows might not occur every year and because results will need to be evaluated, effects of these flows could not be integrated into the summary of impacts on each resource. However, a general range of impacts can be predicted for affected resources.

During years when they occur, endangered fish research flows would have impacts on water and fish similar to those described for the Seasonally Adjusted Steady Flow Alternative. These research flows would not be expected to result in any additional impacts on cultural resources, air quality, or endangered and other special status species (other than native fish). Impacts on sediment, vegetation, wildlife and habitat, recreation, and hydropower potentially would increase up to the level of impacts described under the Seasonally Adjusted Steady Flow Alternative.

Power

As regional population increases, the demand for electric power is expected to increase. Both public and private utilities plan for this eventuality by building new powerplants to meet expected demand. Also, there presently are a number of existing regional powerplants that are not being used to their full capacity.

A reduction in peaking power production at Glen Canyon Dam would have little short-term economic effect since existing facilities and energy conservation measures could satisfy short-term demand. In the long term, any reduction in peaking power capability at Glen Canyon Dam would mean that the demand for electricity would exceed the system's ability to supply electricity sooner than presently envisioned. As a result, some least-cost combination of thermal plants and energy conservation measures would be implemented sooner than planned. The economic impact (cost to society) of these actions has been estimated to range between minus \$1.5 million and plus \$123.5 million annually (see analysis of POWER impacts in this chapter).

Glen Canyon Dam is the least-cost source of peaking power in the affected region. Loss of peaking power generation at Glen Canyon Powerplant will increase wholesale and retail prices by some degree. There are two reasons for this increase.

First, CRSP project costs are prorated over the number of units of peaking power sold. Loss of generation capacity means that fewer units of power can be produced and sold. All other things being equal, this will cause the price per unit of available CRSP capacity to increase. The wholesale price is expected to increase by 23.3 percent under the preferred alternative.

Second, to the extent that a utility's allocation of CRSP power is reduced, affected utilities must purchase higher-cost replacement power from alternative suppliers. These additional costs will be passed on by utilities to their customers.

Rate impacts would vary substantially by supplier and by geographical location, since the extent to which wholesale power rates affect retail power rates depends on the amount of CRSP power used by a utility. Rate increases would be relatively small for a retail customer whose utility receives a relatively small portion of its power from CRSP. However, retail rate increases would be nearly as much as or more than the wholesale rate increase for a retail customer whose utility receives a substantial portion of its power from CRSP.

The impact of increases in power rates in the affected region potentially would be more significant for some economic sectors than estimates of average impact show. For example, any increase in the price of CRSP power increases the cost of irrigation, a significant part of agricultural production costs in this arid region. Consequently, the effective impact of any rate increase for irrigators may be quite large.

Agricultural producers cannot increase their prices to compensate for higher water costs. In the short run, farmers are likely to respond to such increases by applying less water, producing crops that require less water, and/or removing less suitable land from production. In the long run, some irrigation districts and producers may install more water-efficient irrigation systems or systems that use alternative fuels such as natural gas, or they may cease production altogether.

Western commissioned a study of the agricultural sector that focused on power marketing conditions very similar to the preferred alternative described in this EIS. Study results suggest that net farm income in the region would decrease by almost 0.41 percent (U.S. Department of Energy, 1994). Supporting subregional analyses indicate that there are small areas that may experience impacts exceeding this (Flaim, Howitt, and Edwards, 1994). Nonetheless, the expected loss of net income in the agricultural sector would be limited.

Air Quality

Although total emissions from all new and existing powerplants may increase during the day there would be an even greater reduction of emissions at night because Glen Canyon Powerplant and additional new, more efficient powerplants would be producing more power at night. Therefore, the net effect on regional air quality under all restricted fluctuating and steady flow alternatives would be a slight reduction in emissions.

UNAVOIDABLE ADVERSE IMPACTS

None of the alternatives are expected to result in unavoidable adverse impacts to downstream resources relative to no action. However, unavoidable loss of peaking power would result from implementation of any of the restricted fluctuating or steady flow alternatives. These impacts are discussed in detail in the HYDROPOWER section of the chapter.

The existence of Glen Canyon Dam has resulted in unavoidable adverse impacts to most cultural resources in the study area. These impacts are discussed in this chapter and in the accompanying compliance documentation in attachment 5.

RELATIONSHIP BETWEEN SHORT-TERM USES AND LONG-TERM PRODUCTIVITY

Under the restricted fluctuating and steady flow alternatives, there would be a tradeoff between peaking power and long-term sediment stability and, therefore, the stability of those resources linked to sediment (see discussion of resource linkages in chapter III).

IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

Peaking power production foregone on a given day under any alternative would be irretrievably lost. Any loss of archeological sites also would be irretrievable.

INDIAN TRUST ASSETS

Bureau of Reclamation policy is to protect American Indian Trust Assets from adverse impacts of its programs and activities when possible. Indian Trust Assets are property interests held in trust by the United States for the benefit of Indian Tribes or individuals. Lands, minerals, and water rights are common examples of trust assets.

The United States has a trust responsibility to protect and maintain rights reserved by or granted to Indian Tribes or individuals by treaties, statutes, and executive orders. This responsibility is sometimes further interpreted through court decisions and regulation. Although there is no concise legal definition of Indian Trust Assets, courts have traditionally interpreted them as being tied to property.

No adverse impacts to Indian Trust Assets are anticipated from the preferred alternative. However, flood frequency reduction measures for other alternatives may include dedicating 1 million acre-feet of Lake Powell space to flood control. The Navajo Nation is concerned that this flood frequency reduction method would prevent the full development of the Navajo Indian Irrigation Project.

Reclamation has concluded that Indian cultural items and resources are located within the river corridor. For all ancestral tribes of the area, the possibility exists for discovery of items identified in the Native American Graves Protection and Repatriation Act of 1990. These items, defined as associated and unassociated funerary objects, sacred objects, and objects of cultural patrimony, are the property of the affiliated Native American group or Indian Tribe. Potential impacts to human remains and objects are addressed in the Programmatic Agreement on Cultural Resources and accompanying monitoring and remedial action plan (see attachment 5).

The Hualapai Tribe has asserted that there are Indian Trust Assets within the reservation boundary and that these are affected by dam operations. The claimed resources include fish, vegetation, wildlife, and cultural resources. Reclamation does not agree that trust assets are affected because, in Reclamation's opinion, dam operations do not affect reservation lands. Reclamation concluded that the restricted fluctuating and steady flow alternatives (including the preferred alternative) would have beneficial impacts on fish, vegetation, wildlife, and cultural resources relative to the No Action Alternative. A detailed analysis of the impacts on these resources under each alternative is presented earlier in this chapter.

Other Concerns

The Federal Government's responsibilities to and concerns about Indian people are broader than Indian Trust Assets; they also include economics and cultural resources.

The Navajo Tribal Utility Authority, which provides service to the majority of electricity consumers on the Navajo Reservation, purchases about a fourth of its power capacity from Western. Navajo Agricultural Products Industries also receives capacity and energy from Western as part of the Navajo Indian Irrigation Project. Dam operations that result in reduced generating capacity would impact energy rates to Western's customers and, in turn, Navajo electricity consumers.

No measurable economic impacts on Native American-owned or operated recreation enterprises were identified (see RECREATION in this chapter).

Some impacts to cultural resources would likely continue in the future because of the existence of Glen Canyon Dam, regardless of how it is operated. The No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives are expected to result in greater impacts to archeological sites and traditional cultural properties and resources than the other alternatives (see CULTURAL RESOURCES in this chapter).

In cooperation with involved entities, Reclamation participated in developing a programmatic agreement that documents how the Federal Government will protect archeological sites and traditional cultural properties within the geographic area affected by Glen Canyon Dam operations. The involved entities included:

- Advisory Council on Historic Preservation
- Arizona State Historic Preservation Officer
- National Park Service
- Havasupai Tribe
- Hopi Tribe
- Hualapai Tribe
- Kaibab Paiute Tribe
- Navajo Nation
- San Juan Southern Paiute Tribe
- Shivwits Paiute Tribe
- Zuni Pueblo

As a component of the programmatic agreement, Reclamation is coordinating plan formulation for the continual monitoring of cultural resources. This Monitoring and Remedial Action Plan outlines a step-by-step program to address any resource degradation identified by the monitoring process. Any future impacts to archeological sites and traditional cultural properties would be minimized through the implementation of the programmatic agreement (attachment 5).

IMPACTS ON OTHER FEDERAL AND NON-FEDERAL PROJECTS AND PLANS

Inexpensive CRSP power has allowed agricultural development to flourish in this arid region. CRSP power is used extensively by participating irrigation districts and federally funded irrigation projects such as the Central Arizona Project.

Far-ranging effects on the economic and financial viability of irrigation projects in the region may result from increases in CRSP power rates. These increases may contribute to the insolvency of marginal producers and this, in turn, may threaten existing project repayment. Increases in the price of power may make planned marginal projects economically or financially infeasible.

The amount of electricity produced off-peak would not be reduced by the preferred alternative and may, in fact, be increased. Therefore, the effect on the power rates, and thus the economic and financial viability of existing and future projects, is difficult to project.

Management Plans

The alternatives are not expected to cause changes in NPS or tribal management plans.

Western's Power Marketing

Western may have to change the way power is marketed in the region as a result of changed operations at Glen Canyon Dam. Western is currently preparing an EIS to evaluate systemwide power marketing and allocations.

State of Arizona

Management of the Glen Canyon trout fishery may likely change in the future under any of the restricted fluctuating or steady flow alternatives. Stocking could be reduced since there would be decreased stranding of adults, improved spawning, enhanced recruitment, and increases in growth rates. Potential improvements in the quality of the fishery also would provide the opportunity for relaxed fishing regulations.